APPROVAL SHEET

Title of Thesis: THERMAL RESPONSES TO EXERCISE AND THEIR RELATIONSHIP TO PHYSICAL CONDITIONING

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Title of Dissertation: Thermal Responses to Exercise and their Relationship to Physical Conditioning

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ABSTRACT

Heat acclimatization is acquired in men during repeated long term steady-state work in a heated environment. Physically conditioned men who are not environmentally heat acclimated have been reported to have some similar thermal responses to environmentally heat acclimated men (e.g. enhanced distribution of blood flow in the skin, increased sweating, and a lower accumulation of internal temperature). However, the mechanisms by which and the extent to which physical conditioning affects these temperature responses is unclear. The relationship of physiological variables commonly affected by conditioning (e.g., maximum oxygen consumption ($\dot{V}O_2max$) and percent fat) to temperature responses is also obscure.

Specific aims of this study were: 1) to identify the acute (non steady-state) exercise-induced thermal responses of men with different levels of physical conditioning; 2) to identify the significant relationships between any differences found in these thermal responses and differences in other selected physiological responses of men with different levels of conditioning; and 3) to identify the applicability of the various mathematical formulae commonly used in the field of thermal stress to this study.

In this investigation, 53 male subjects placed in groups by level of physical conditioning were studied. The three groups consisted

of 1) marathoners (men running greater than 50 miles per week), 2) joggers (men running 10-15 miles per week), and 3) sedentary men (men who were on no routine exercise program). Each subject was exercised according to the Bruce protocol. Cardiopulmonary function was closely monitored and thermal responses (rectal temperature and temperature at nine individual skin sites) were recorded at rest, during exercise, and for one hour post exercise.

Several major points about thermal responses to exercise and their relationship to physical conditioning were identified:

1) Differences in temperature responses of men with different levels of conditioning can be identified within a few minutes of acute exercise.
2) Internal (rectal) temperature increases in all groups during exercise, but better conditioned individuals have lower rectal temperature and lower rates of heat accumulation at any given workload.
3) Marathoners dissipate internal heat better than joggers or sedentary men. In general, joggers resembled sedentary men in their thermal responses more than they resembled marathoners.
4) Physical conditioning affects skin temperature responses at selected sites during exercise and recovery. This is missed when using mathematical formulae derived for the purpose of identifying "total" body thermal response.
5) Changes in body temperature responses with physical conditioning can be related with changes in maximum oxygen consumption and body fat.

These findings demonstrate that physical conditioning alone increases the ability to compensate against heat. The altered thermal responses which reflect this increased compensation can be identified during acute short-term exercise in a thermoneutral environment.

THERMAL RESPONSES TO EXERCISE AND
THEIR RELATIONSHIP TO PHYSICAL CONDITIONING

by

Guy R. Banta

Dissertation submitted to the faculty of the Department of Physiology Graduate Program of the Uniformed Services University of the Health Sciences in partial fulfillment of the requirements for the degree of Doctor of Philosphy 1982

DEDICATION

To my mother and father for their love,
support and their dreams.

To my bride, for her support, her sacrifices,
and her love.

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INTRODUCTION

Most studies[3,9,27,32,34,54,82,95,99] of thermal response have addressed the combination of exercise-induced metabolic heat load and environmental heat load. These investigations have been directed toward repetitive exposures and steady state work rates in high heat environments. Many of these studies have also been directed at developing exposure indices, improved clothing, and better working environments for maximizing ability to compensate to high heat loads. Since earlier investigators[33,77,91] have reported that better conditioned individuals adjust to environmental heat loads better than non-conditioned individuals, this study focuses on the early thermal responses of men with different levels of conditioning.

The amount of acute exercise, or the amount of short term work, that an individual can accomplish is limited primarily by three factors: (1) How much blood is pumped to the working tissues; (2) How much oxygen (O_2) is carried in that blood; and (3) How rapidly the oxygen is utilized by the working tissues. Conditioning markedly improves blood supply to working muscles and the ability of working tissue to utilize oxygen.

The maximum oxygen consumption ($\dot{V}O_2max$) or "aerobic power," expressed in ml of oxygen per kg of body weight per min ($ml\ O_2 \cdot kg^{-1} \cdot min^{-1}$), is a reproducible physiological end point useful for quantifying the level of conditioning. The $\dot{V}O_2max$ increases with conditioning.[6] This increase in $\dot{V}O_2max$ is due to a greater maximum cardiac output and the enhanced ability of working tissue to utilize oxygen. The greater maximum cardiac output in conditioned individuals

is accompanied by an increased stroke volume and a decreased heart rate at any given workload.[29,30,83] The enhanced utilization of oxygen by the tissues is due in part to an increase in capillary density.[19] The increased number of capillaries per cross sectional area of working muscle decreases diffusion distance between the blood vessel and the muscle fibers thereby enhancing oxygen delivery. Oxidative potential of the muscles also increases. Pyruvate and fatty acids can be metabolized more rapidly because of an increase in the concentration and activity of mitochondrial enzymes with training.[19,51,86]

These changes and the increased maximum O_2 consumption allow the trained individual to work longer and harder aerobically. Therefore, the level of work where the metabolic demands of exercise can no longer be met totally aerobically is increased with training.

Buskirk[20] has recently presented a literature review on temperature regulation with exercise. The review clearly indicates that heat production during exercise is directly related to workload. Nielsen's[69] classic work identified absolute work as the amount of oxygen consumption (liters $\cdot$ min^{-1}) necessary to accomplish the work task. Åstrand[4] added that the expression of workload may be better identified as relative work, i.e., the percentage of $\dot{V}O_2$max (ml O_2 $\cdot$ kg^{-1} $\cdot$ min^{-1}) used to accomplish the work task. Saltin and Hermansen[86] studied seven subjects with different maximum oxygen consumptions to determine whether internal temperature is related to absolute workload or relative workload. Their research revealed three basic results. 1) Rectal and esophageal temperatures of the subjects at comparable percentiles of their $\dot{V}O_2$max, but different absolute work levels,

were comparable. 2) Highly conditioned subjects produced more than twice as much heat as the less conditioned subjects. 3) Better conditioned individuals must, therefore, dissipate heat better than other subjects.

When an individual exercises at a given workload he expends a corresponding given amount of energy, whether that workload is moving an external load or moving body weight. Of the total energy expended, only about 25 percent is used for accomplishing work while the rest is lost as heat.[6] Both the energy utilized and the heat produced are thus directly related to the workload. This is true whether the energy is supplied aerobically, anaerobically or by a combination of the two. Although resting oral temperature varies from 35.8°C to 37.5°C and resting rectal temperature is less than 1°C higher[18], the heat load generated by exercise may elevate rectal temperature to as high as 41.9°C.[57]

During exercise, heat production and heat transfer are greater in those regions in which muscle activity is the greatest; for example, in the lower extremities during running.[72] The increased temperature in the large leg muscles with running is easily transferred to the pelvic region by the blood draining through the pelvic region and it is easily monitored by rectal temperature probes. Because of this, the T_{re} may be more related to lower extremity muscle temperature than to total core temperature and its reliability as an indicator of general internal temperature has been debated.[24,48,60,68] However, it is the most widely used indicator of core temperature change with exercise. Another characteristic of rectal temperature response to

exercise is the delay between the onset of exercise and increases in T_{re}.[36] This results from the delay in transfer of heat from working muscles in the legs to the rectal area.

Tympanic membrane temperature (T_{ty}) has also been used to indicate internal temperature, or more specifically brain, temperature.[6] Esophageal temperature (T_{es}) at the level of the left atrium is also often used as a measurement of internal temperature. However, due to the ease of placement of a rectal probe and the relative relationship of T_{re} with the other measures of internal temperature (T_{ty} and T_{es}),[87] T_{re} has been the most conventional site for monitoring internal temperature during work.

The "body thermostat" which is located in the preoptic region of the anterior hypothalamus responds to the temperature of blood flowing through the hypothalamus and to afferent neural impulses from the skin receptors.[10,89,90] The warm and cold receptors of the skin respond to a combination of ambient temperature and the temperature of blood flowing through the skin. Temperature inputs from other regions of the body are also present, but the hypothalamic "thermostat" sensitivity to these temperature inputs is minimal compared to its sensitivity to input from the hypothalamus and skin receptors.[20] A sustained increase in internal temperature after exercise may be seen which may not be due solely to increased metabolic heat production during exercise. The body thermostat may be reset at a higher temperature and contribute to heat retention after exercise.[5,11,47,67,87,89]

Heat is dissipated by three mechanisms: 1) radiation (R), 2) conduction/convection (C), and 3) evaporation (E). Radiation is

the giving off of heat as infrared rays. Conduction is the direct transfer of heat, including transfer of heat from the outermost layer of the skin to the adjacent layer of air. Conduction to the air stimulates convective currents which then carry heat away from the body. Conduction/convection is increased by increased movement of air across the skin by either movement of the air or movement of the body through the air. Evaporation cools the skin as heat is dissipated when sweat is converted to water vapor and evaporated. At rest in a comfortable thermal environment, the body loses approximately 60% of its heat by radiation, 15% by conduction/convection and 25% by evaporation.[46] During exercise, the percentage of heat loss by all three mechanisms is altered. The largest fraction of heat is still lost by radiation and conduction/convection during acute exercise, but with prolonged exercise the greatest fraction of heat is lost by evaporation.

At a thermal steady state, heat production is exactly balanced by heat loss[97]:

$$M \pm R \pm C - E = \emptyset \quad (M = \text{metabolic heat load})$$

However, with moderately high levels of exercise, especially in hot environments, heat accumulates and heat storage (S) occurs:

$$M \pm R \pm C - E = S$$

Heat storage during exercise results in a gradual increase in body temperature despite increases in the activity of heat dissipation mechanisms.

At the onset of exercise, blood is shunted to the working muscles by dilitation of vessels to those muscles and constriction

of vessels to the skin and viscera.[12,13,55,83] However, with accumulation of heat, blood flow is returned intermittently to the periphery to prevent marked increases in body temperature.[12,16,55] The shunting of blood to the skin efficiently transfers heat to the subcutaneous regions because of the high heat capacity of blood (each liter of blood shunted to the skin dissipates 4 kcals or more).[6,43] This increase in peripheral blood flow is thought to be initiated by a vasoconstrictor inhibition impulse and/or vasodilator impulse to the cutaneous vasculature.[6,80] The exact mechanism of this action has been an area of considerable controversy.[14,15,31,44,66,83,94] Vasodilator metabolites such as bradykinin, which has been found in sweat, may also be involved in the increased cutaneous blood flow.[31,45]

As internal temperature increases and skin temperature is increased by increased blood flow, the sweat glands are stimulated and evaporative cooling begins.[45,66] Each milliliter of sweat evaporated dissipates 0.58 kcal (heat of vaporization of water). The maximum sustainable sweat rate for a 70 kg man is 1 liter/hr, which represents approximately 600 kcals/hr.[37] However, man can sweat as much as 3 liters/hr over short periods of time and quickly become dehydrated.[66] This rate of sweating cannot be sustained. Like skin blood flow, sweating activity is stimulated by hypothalamic and skin receptors.[10,20,63] An increase in sweat rate during work is primarily related to increased internal temperature.[45,71] The rate of sweating increases as T_{re} increases between 36.8°C and 38.3°C.[100] Above 38.3°C sweating rate is maximal. Below 36.8°C sweating is inhibited. Nadel, Stolwijk, and Mitchel[62,64] recognized that various

body regions have different sweat rates and different sensitivities to thermal stimulation of sweating. Each body region appears to have its own characteristic internal temperature threshold for initiation of sweating.[20]

Skin temperature (T_{sk}) is dependent on heat transferred to the skin by skin blood flow and conduction and heat lost to or gained from the external environment. Skin temperature can span a large range both at rest and during exercise, depending on the metabolic and environmental heat loads. Most studies evaluate "total body" skin temperature and thermal response rather than "specific body region" skin temperature and thermal responses. A number of mathematical formulae have been derived to express these total body thermal responses as accurately as possible. The mean skin temperature ($\bar{T}_{sk}$) and other indices of total body thermal responses are frequently used in current literature.[21,49,64,67,75,80,81,97] Mean skin temperature can be calculated by a number of mathematical formulae. The mean weighted skin temperature (MWST) is calculated by multiplying the surface temperatures of specific regions by the fraction of the body surface that that area represents and then adding the products to get the MWST. The percentage of the total body surface assigned to each body segment is generally derived by Dubois' "Linear Formula."[26] The following are commonly used mean weighted skin temperature (MWST) equations:

A. Burton's[21] M_3WST (3 points)

M_3WST = (chest x 0.50)+(calf x 0.36)+(lower arm x 0.14)

B. Newburgh and Spealman's[68] M_4WST (4 points)

M_4WST = (chest x 0.34)+(thigh x 0.33)+(leg x 0.18)+ (lower arm x 0.15)

C. Hardy and Dubois'[49] M_7WST (7 points)

M_7WST = (forehead x 0.07)+(chest x 0.35)+(thigh x 0.19)+ (calf x 0.13)+(sole x 0.07)+(lower arm x 0.14)+ (palm x 0.05)

The simple arithmetic mean of the skin temperature at several sites has also been used for quantifying the total skin temperature.[54,17,73] Adams[2] compared arithmetic mean skin temperatures with the Hardy and Dubois M_7WST formula in a variety of heat load studies. He found them to agree within 0.25°C and concluded that, because of the ease of computation, arithmetic mean may be used instead of the MWST to determine mean skin temperature.

Another commonly used temperature response equation, mean body temperature ($\bar{T}_b$),[22] incorporates both the T_{re} and the $\bar{T}_{sk}$ (MWST):

$$\bar{T}_b = 1/3\ \bar{T}_{sk} + 2/3\ T_{re}$$

The $\bar{T}_b$ equation is frequently used to calculate the change in total body heat content or heat storage (ΔS):[22]

$$\Delta S = 0.83 \cdot \text{body mass} \cdot \Delta\ \bar{T}_b$$

where 0.83 is the specific heat content of human tissue ($kcal \cdot kg^{-1} \cdot {}^{\circ}C^{-1}$) and body mass is expressed in kg.

These various mathematical formulae, because they express "total" thermal responses, may miss more subtle thermal responses which vary by skin region. Further, the applicability of these equations to acute short-term (transient) exercise stress in thermoneutral environments, rather than to long-term steady-state work in

thermally stressed environments, is uncertain. This study examines specific skin area responses to acute exercise and the applicability of various mathematical heat stress equations to this type of stress.

On repeated exposure to high levels of environmental heat, subjects develop increased heat acclimatization.[28,32,84,100,101] Approximately 90% acclimatization appearing in a week has been reported.[39] However, only about 52% acclimatization can occur when a high vapor pressure (relative humidity) is present and 80-90% acclimatization is seen only when a low vapor pressure exists.[25] Full acclimatization (100%) takes more than a week.[39,82] In the heat acclimated individual, blood flow is believed to be more efficiently distributed.[81] Early skin vasodilator activity allows increased cutaneous blood flow.[66,81] Acclimatization also increases the sweating response.[66,81,99] Sweating in heat acclimated subjects begins at a lower internal temperature, the onset is more sudden, and the volume of sweat that can be produced is increased. An increase in sensitivity of the central drive (hypothalamus plus skin receptors) for sweating probably develops.[62,81] As skin blood flow and sweating increase with acclimation, heat dissipation increases and internal temperature decreases. These cardiovascular and sweating changes allow an individual to perform a given workload in a heated environment longer than a non-acclimated individual with the same cardiovascular fitness. Similar physiological changes were found in well-conditioned individuals who were not environmentally heat acclimated.[33,37,76,80,90] They had a lower T_{re}, a lower rate of rise of T_{re} for a given heat load, an enhanced cutaneous blood

flow, and an increased sweating response. It is unclear, however, to what extent physical conditioning affects these temperature responses.

The specific aims of the present study were to address the following questions:

1. What are the acute (non-steady state) exercise-induced thermal responses of men with different levels of physical conditioning?
2. What relationships are there between any differences found in these thermal responses and differences in other selected physiological responses of men with different levels of conditioning?
3. How applicable to the study of acute metabolic thermal responses are the equations used for evaluating the physiological responses to heat?

The answers to these questions will add to our understanding of the physiological responses to heat generated by acute (transient) non-steady state work and to our understanding of the role of physical conditioning in the adaptation of these responses.

MATERIALS AND METHODS

Subjects

Fifty-three men, categorized by level of conditioning, were used as test subjects. All subjects gave their informed consent to participate (see Appendix 1). Sixteen marathoners who were running more than 50 miles a week were considered highly conditioned. Seventeen joggers who were running 10-15 miles a week were considered moderately conditioned. Fifteen individuals who followed no routine exercise program were classified as sedentary. The three groups were matched as closely as possible according to age and height; matching for weight and percent body fat was also attempted. All subjects were non-smokers and had less than 25% body fat. Each subject was studied on a separate day following 12 hours of fasting and abstention from vigorous exercise. Subjects in each group were studied at various times of the year to decrease the influence of seasonal acclimitization on the results (see Appendix 2). The study was conducted in a thermoneutral environment which was confortable for working men. The average laboratory (room) temperature and relative humidity of all subject test days was 23°C and 45% respectively in still air.

History and Physical

A medical evaluation (Standard Forms 93 and 88; Appendix 3 and 4) and a 12 lead electrocardiogram were performed on each subject. Potential subjects with a history or physical evidence of significant medical problems that would limit their capacity to perform exercise or increase their risk of exercise were excluded from the study.

Body Fat determination

Percent body fat was determined by skinfold measurements according to Pollack et al. (cf. equations p. 19).[78] Measurements were taken with a skinfold caliper (Appendix 5) manufactured to give a constant pressure of 10 gm/sq mm and read to the nearest two tenths mm. The instrument was used by picking up a fold of skin and subcutaneous tissue between the thumb and forefinger of the left hand and pulling it away from the underlying muscle. While continually holding the fold, the calipers were applied just below the fingers (Appendix 6). Full pressure of the caliper was exerted by removal of the fingers of the right hand from the trigger-lever. Measurements at each location were repeated until three successive readings were within 0.2 mm. Skinfold measurements were taken at seven anatomical sites on the right side of the body (Appendix 7):

1. Chest - a diagonal fold over the pectoralis major muscle midway between the nipple and shoulder crease.
2. Subscapular - a diagonal fold just below the inferior border of the scapula.
3. Triceps - a vertical fold midway between the acromion and olecranon processes.
4. Abdomen - a vertical fold approximately 2.5 cm to the right of the umbilicus.
5. Suprailiac - a horizontal fold just above the iliac crest.

6. Front thigh - a vertical fold midway between the greater trochanter and patella.

7. Axilla - a vertical fold on the lateral side of the thorax, on a line bisecting the armpit and hip at a level equal to the xiphoid process.

Electrocardiogram (ECG)

The electrocardiogram (ECG) was monitored at rest, during exercise and during recovery using a Quinton Instrument Model 633 3-Channel ECG recorder and monitor (Appendix 8). Lead II, AVF, and V5 were monitored continuously and heart rate was continuously displayed digitally.

To attain proper conductance and transmission of electrical potential, the skin sites for electrode placement were abraded and cleansed with alcohol soaked gauze. When the skin was dry, tincture of benzoin was applied as an adhesive for placement of the pre-gelled electrodes. Electrodes were placed on the following sites:

Limb leads (Appendix 9)

a. Right and left arm - leads were placed in the right and left midclavicular lines just below the clavicle.

b. Right and left leg - leads were placed on the right and left anterior abdomen just above the iliac crests, and on a line running between the umbilicus and the anterior superior iliac spine.

Chest Leads (Appendix 10)

a. V_1 and V_2 were placed over the fourth intercostal space to the right and left margins of the sternum respectively.

b. V_4 was placed over the fifth intercostal space in the midclavicular line.

c. V_3 was centered on a line connecting V_2 and V_4.

d. V_5 and V_6 were placed on a horizontal line from V_4. V_5 was placed at the anterior axillary line and V_6 at the midaxillary line.

Respiratory and Metabolic Measurements

Gas analyses were performed at rest, during exercise, and during recovery using a Beckman Metabolic Measurement Cart (MMC) (Appendix 11). The following measurements and calculations were made and recorded every 30 or 60 sec by the MMC:

Minute Ventilation ($\dot{V}_E$) : The volume of gas exhaled by the subject in one minute, expressed in liters $\cdot$ min^{-1}.

Respiratory Rate (F) : The frequency of breaths per minute.

Tidal Volume (TV): The volume of gas exhaled by the subject in each breath, expressed as ml $\cdot$ $breath^{-1}$.

Oxygen Consumption ($\dot{V}O_2$): Expressed in two forms; ml $O_2 \cdot min^{-1}$ and ml $O_2 \cdot kg^{-1} \cdot min^{-1}$.

METS: A multiple of the theoretical resting rate of metabolism (1 met = 50 kcal $\cdot$ $m^{-2} \cdot hr^{-1}$).[66]

Carbon Dioxide Production ($\dot{V}CO_2$): The volume of CO_2 produced and expired, expressed in ml $\cdot$ min^{-1}.

Respiratory Exchange Ratio (RQ): The ratio between $\dot{V}CO_2$ and $\dot{V}O_2$.

Calibration procedures as outlined by the MMC manufacturer[8] were conducted within 5 minutes of the start of the exercise test and within 5 minutes after completion of all respiratory measurements. A difference in calibration of less then one percent was considered acceptable.

Temperature Monitoring

Thermal responses at rest, during exercise, and during recovery were monitored by recording rectal temperature and skin temperature at nine different sites. Rectal temperature was monitored using a YSI series 400 rectal temperature probe inserted to 10 cm past the external anal sphincter and held in place using a harness and belt (Appendix 12). Skin temperatures were monitored using YSI series 400 skin thermistors (Appendix 13) placed on the following skin sites and held in place by porous tape (Appendix 14).

1. Center of the forehead
2. Over the left pectoralis major muscle midway between the nipple and shoulder crease.
3. Medial side of the left forearm midway between the wrist and antecubital fossa.
4. Dorsal surface of the left hand.
5. Left upper quadrant of the abdomen.
6. Anterior portion of the left thigh (over the quadriceps muscles) midway between the greater trochanter and patella.

7. Posterior-lateral portion of the left calf (over the gastrocnemeus muscle) approximately 13 cm below the popliteal fossa.
8. Slightly medial and posterior to the medial border of the left scapula.
9. Left lumbar region just superior to the iliac crest.

Temperature measurements were monitored and recorded from a YSI model 46 Tele-thermometer (Appendix 15) with readability of ± 0.05°C. All thermistors were calibrated in a water bath before use and specific skin thermistors were designated for use at specific sites to insure accuracy and comparability of thermal data. Temperatures at rest and during exercise were recorded when subjects were standing and during recovery when subjects were recumbent.

Blood Analyses

Blood samples were drawn for analyses on each subject at rest, at the end of exercise, and one hour after exercise. Most analyses performed were for collaborative studies on blood chemistry changes with acute exercise in men. This study used only minimal amounts of the data.

Rest

Before the first blood sample was drawn, each subject remained in a blood donors chair approximately 15-20 minutes.

Exercise Protocol

Subjects were exercised on a treadmill (Appendix 16) utilizing the Bruce protocol.[58] This protocol is a continuous multi-staged treadmill test with increases in speed and grade every three minutes.

Bruce Protocol

Stage	Duration (minutes)	Elapsed Time (minutes)	Speed m/sec	(mph)	Grade (%)
1	3	1-3	0.76	1.7	10
2	3	4-6	1.12	2.5	12
3	3	7-9	1.52	3.4	14
4	3	10-12	1.89	4.2	16
5	3	13-15	2.24	5.0	18
6	3	16-18	2.46	5.5	20
7	3	19-21	2.68	6.0	22

Each subject exercised to their maximum. Criteria used to determined that subjects reached their maximum effort prior to temination of test were: 1) indication of exhaustion by subject; 2) plateauing

of heart rate; 3) minimal further increase in $\dot{V}O_2$; and 4) respiratory exchange ratio greater than 1. The ECG and MMC were monitored continuously during the exercise. "Exercise" T_{re} and the 9 T_{sk} were recorded every five minutes during exercise and "End" values were recorded at maximum exercise.

Recovery

After stepping off the treadmill, each subject was again seated in the blood donor chair and blood was drawn within 1 minute of the start of the recovery period. The ECG and MMC were monitored for the first 20 minutes of recovery. "Recovery" T_{re} and T_{sk} were recorded every five minutes for 60 minutes of recovery. At one hour post exercise, a final recovery blood sample was drawn and the test was considered completed for that subject.

Equations

The following equations were used to define 19 thermal variables used in evaluating portions of the data collected on each subject (M; A; %F; M_7AST, M_5AST, M_4WST and M_3WST; M_5AT_b; M_4WT_b and M_{3WTb}; M_5AH_{grad}, M_4WH_{grad} and $M_3\ WH_{grad}$; $M_5A\Delta S$, M_5AS, $M_4W\Delta S$, M_4WS; $M_3W\Delta S$ and M_3WS).

1. <u>Metabolic energy cost (M)</u>[35]

$$M = 1.5W + 2.0\ (W+L)\ (L/W)^2 + \eta\ (W+L)\ (1.5V^2 + 0.35VG)$$

where: M = metabolic rate, watt kcal/min

W = Body weight, kg

L = External load, kg

V = velocity (walking/running speed), m/s

G = Grade [slope], %

η = Terrain factor, (η = 1.0 for treadmill walking)

Since the external load (clothes) was negligable for our subjects and $\eta = 1$ for treadmill walking, the metabolic energy equation was simplified as follows:

$$M = 1.5\ W + 1.5\ W\ (V^2 + 0.35\ VG)$$

2. Surface Area (A)[26]

$$A = W^{0.425} \times H^{0.725} \times .007184$$

where: A = surface area in m^2

W = weight in kg

H = height in cm

3. Percent Body Fat (%F)[78,88]

a. Sum 7 = Sum of 7 skinfolds = Chest+Abdomen+Axilla+Subscapular+Suprailiac+Triceps+Thigh

b. Body density = D = 1.112 - 0.00043499 (sum 7) + 0.00000055 [(sum 7)^2] - 0.00028826 (age) yrs

c. Percent body fat = %F = [(4.95/D) - 4.5] x 100

4. Mean Skin Temperature ($\bar{T}_{sk}$)

a. Arthmetic Mean 7 point Skin Temperature (M_7AST)[2]

$$\frac{\text{Forehead + Chest + Abdomen + Forearm + Hand + Thigh + Calf}}{7}$$

b. Arithmetic Mean 5 point Skin Temperature (M_5AST)

$$\frac{\text{Forehead + Chest + Forearm + Thigh + Calf}}{5}$$

c. Mean Weighted Skin Temperature (4 points) (M_4WST)[67]

(Chest x 0.34) + (thigh x 0.33) + (leg x 0.18) +

(lower arm x 0.15)

d. Mean Weighted Skin Temperature (3 points), (M_3WST)[21]

(Chest x 0.50) + (Calf x 0.36) + (Lower Arm x 0.14)

5. Mean Body Temperature ($\bar{T}_b$)[22]

$\bar{T}_b = 1/3\ \bar{T}_{sk} + 2/3\ T_{re}$

a. Mean 5 (Arithmetic) Body Temperature

$M_5AT_b = 1/3\ \bar{T}_{sk} + 2/3\ T_{re}$

where: $\bar{T}_{sk} = M_5ST$

b. Mean 4 (Weighted) Body Temperature

$M_4WT_b = 1/3\ \bar{T}_{sk} + 2/3\ T_{re}$

where: $\bar{T}_{sk} = M_4WST$

c. Mean 3 (Weighted) Body Temperature

$M_3WT_b = 1/3\ \bar{T}_{sk} + 2/3\ T_{re}$

where: $\bar{T}_{sk} = M_3WST$

6. Heat Gradient

$H_{grad} = T_{re} - \bar{T}_{sk}$

a. Mean 5 (Arithmetic) Heat Gradient

$M_5AH_{grad} = T_{re} - \bar{T}_{sk}$

where: $\bar{T}_{sk} = M_5ST$

b. Mean 4 (Weighted) Heat Gradient

$M_4WH_{grad} = T_{re} - \bar{T}_{sk}$

where: $\bar{T}_{sk} = M_4WST$

c. Mean 3 (Weighted) Heat Gradient

$M_3WH_{grad} = T_{re} - \bar{T}_{sk}$

where: $\bar{T}_{sk} = M_3WST$

7. Change in Heat Content during a Time Interval (Heat Storage ΔS) [22,41,42]

$\Delta S = 0.83 \cdot \text{Mass} \cdot \Delta \bar{T}_b$

where: 0.83 = specific heat of body tissue ($\text{kcal} \cdot \text{kg}^{-1} \cdot °\text{C}^{-1}$)

mass = weight of subject in kg

$\Delta\bar{T}_b$ = change in mean body temperature at time t ($\bar{T}_{bt2} - \bar{T}_{bt1}$)

where: $\bar{T}_{bt1}$ = mean body temperature at start of time interval

$\bar{T}_{bt2}$ = mean body temperature at end of time interval.

When $\bar{T}_{b1} = \bar{T}_{bto}$, i.e., initial resting mean body temperature, ΔS becomes accumulated heat storage (S).

a. Mean 5 (Arithmetic) Change in Body Heat Content and Heat Storage

$M_5A\Delta S = 0.83 \cdot \text{mass} \cdot \Delta \bar{T}_{b(t2-t1)}$ and

$M_5AS = 0.83 \cdot \text{mass} \cdot \Delta\bar{T}_{b(t2-to)}$

where: $\bar{T}_b$ is based on M_5AST

b. Mean 4 (Weighted) Change in Body Heat Content and Heat Storage

$M_4W\Delta S = 0.83 \cdot \text{mass} \cdot \Delta \bar{T}_{b(t2-t1)}$ and

$M_4WS = 0.83 \cdot \text{mass} \cdot \Delta T_{b(t2-to)}$

where: $\bar{T}_b$ is based on M_4WST

c. Mean 3 (Weighted) Change in Body Heat Content and Heat Storage

$M_3W\Delta S = 0.83 \cdot \text{Mass} \cdot \Delta\ \bar{T}_{b(t2-t1)}$ and

$M_3WS = 0.83 \cdot \text{mass} \cdot \Delta\ \bar{T}_{b(t2-to)}$

where: $\bar{T}_b$ is based on M_3WST

Statistical Methods

At the recommendation of the University's statistician, simple univariate statistics were used in the analysis of these data. This form of analysis is better for identifying broad relationships among many variables than is multivariate analysis which is more appropriate for the analysis of a relatively limited number of variables in much larger populations. To use multivariate analysis with a small population size and large number of variables, leads to hypothesis tests with little statistical power.

Statistically significant changes in variables across time (between time points) were determined using the paired Student's t-test. Statistical analyses with unpaired Student's t-test were used to compare the differences between the subject groups. To insure that a type 1 error ($\alpha = 5\%$) was not exceeded using the Student's t-test for three groups of subjects instead of two, the Bonferroni inequality method[93] was applied. The Bonferroni procedure divides the commonly accepted level of significance ($p < 0.05$) by the number of groups compared (i.e., three for this study). This study thus used a level of significance near $p < 0.02$.

Values in tables, results, and discussion are generally given as means ± standard deviations.

Pearson correlation coefficient analysis was used to test relationships between variables where underlying hypotheses suggested meaningful relationships might exist. Correlations were performed for each subject group and for the combination of all three groups.

RESULTS

Subjects

General data on each group of subjects used in this study are presented in Table 1. Age, height, and lean body mass were not significantly different between the groups. However, the joggers and sedentary group had significantly greater body weight, body fat, and surface area than the marathoners. Length of time on the treadmill was greatest for marathoners. Oxygen consumption ($\dot{V}O_2$) (Table 2) was significantly greater in marathoners at rest, at 5 min, 10 min, and at the end of exercise. The $\dot{V}O_2max$ and $\dot{V}O_2$ at the end of exercise were different in all three groups.

Rectal Temperature (T_{re})

Figure 1 shows that T_{re} increased with exercise in all three groups following a five minute lag period. A significant value greater than end occurred within the first few minutes of recovery. This reflected an overshoot from the preceding exercise period followed by a slow return toward resting levels during the remainder of the one hour recovery period.

At rest and during the first ten minutes of exercise, the sedentary group had higher T_{re} than marathoners and joggers (Table 3). During recovery, marathoners generally maintained the highest temperature until 50 minutes post exercise and the joggers and sedentary groups were not significantly different.

As shown in Table 4, the sedentary group increased their rectal temperature more at 10 minutes of exercise than did the marathoners ($p \leq 0.02$). However, at end exercise the marathoners had increased their T_{re} more than either joggers or sedentary men (both $p \leq 0.001$). Rectal temperature peaked at five minutes post exercise (5P) for the marathoners and the sedentary group and at ten minutes post (10P) for the joggers. Marathoners had the greatest increase in rectal temperature after exercise. During the first half of recovery (5P-30P), the sedentary group had the greatest decrease in T_{re} of the three groups, while during the second half of recovery (30P-60P), marathoners had the greatest decrease. One hour after exercise the marathoners still had an elevated rectal temperature but the other two groups did not ($p \leq 0.001$).

Figure 2 shows the relationship of T_{re} to relative aerobic workload ($\dot{V}O_2$). At each five minute interval from rest to end exercise, marathoners had a greater $\dot{V}O_2$, a lower percent of $\dot{V}O_2max$ and a lower T_{re}. Joggers had a greater $\dot{V}O_2$ than the sedentary group only at the end of exercise; however, T_{re} and percent of $\dot{V}O_2max$ were lower at each time point for joggers than for the sedentary group.

Skin Temperature (T_{sk})

Skin temperature responses of different regions of the body during acute, short-term exercise and a one hour recovery period were different. During exercise, all three possible skin temperature responses occurred at various sites; 1) a decrease in temperature, 2) no change in temperature, and 3) an increase in temperature.

During recovery, only two of the possible major skin temperature responses occurred. 1) A peak in temperature within the first few minutes of recovery, followed by a decrease in temperature during the first half of rcovery and an increase and/or plateauing of temperature thereafter. 2) A rapid increase in temperature within the first few minutes of recovery, to reach a stable level significantly higher than the resting level.

Forehead Skin Temperature

Forehead skin temperatures (Tables 5 and 6 and Figure 3) in the groups were similar at rest and responded similarly to exercise. Following exercise, forehead temperatures peaked within the first few minutes of recovery and then decreased until 30 minutes post exercise. During the remaining 30 minutes of recovery, temperatures increased to slightly above resting levels. There were no significant differences between the groups at any time.

Chest Skin Temperature

Chest skin temperatures (Tables 7 and 8 and Figure 4) in all three groups were similar at rest, and responded similarly to exercise. Chest skin temperatures in each group peaked within the first few minutes of recovery. Following this temperature peak, chest skin temperature of the marathoners declined significantly during the first half of the recovery period and then leveled off above resting levels in the second half of recovery. The changes in chest skin temperature during recovery in joggers and sedentary groups were not significant.

Abdomen Skin Temperature

During exercise abdomen skin temperatures decreased in each group (Tables 9 and 10 and Figure 5). The joggers and sedentary men had greater decreases than the marathoners during the first ten minutes. Following exercise, temperatures in marathoners and sedentary men peaked within the first few minutes of recovery; the magnitude of the peaks was small and temperatures did not exceed resting levels. Following this peak, the marathoners' abdomen skin temperature decreased during the first half of recovery while the joggers and sedentary group did not change significantly. During the latter half of recovery, abdomen skin temperatures in each group increased significantly to levels near their resting levels. At rest and during exercise, marathoners had the highest abdomen skin temperature. However, except at the peak which occurred during the first five minutes of recovery, after their longer exercise period, abdominal skin temperatures of the marathoners were not significantly different from the other groups during recovery.

Forearm Skin Temperature

With exercise, forearm skin temperatures decreased significantly in all groups (Tables 11 and 12 and Figure 6). During recovery, temperatures increased within the first few minutes in each group. Rather than falling subsequently, as forehead, chest and abdomen temperatures had, forearm skin temperatures in each group increased in the later stages of the recovery period to plateau 50 min after exercise. Except for marathoners having lower temperatures during

the first half of recovery, forearm temperatures among the groups at rest, during exercise, and during recovery were comparable.

Hand Skin Temperature

Hand skin temperature decreased with exercise in all groups (Tables 13 and 14 and Figure 7). During the first five minutes of recovery following exercise, hand skin temperature did not change significantly. However, during the first half of the recovery period, the temperatures increased in all groups to levels significantly higher than resting levels. During the latter half of the recovery period the temperatures plateaued at levels well above resting levels. At rest and during exercise, marathoners maintained the lowest hand skin temperatures. However, during recovery, there were no significant differences between the groups at any time point.

Thigh Skin Temperature

During the first five minutes of exercise, thigh skin temperatures decreased in all groups (Tables 15 and 16 and Figure 8). During the remainder of exercise, thigh temperature in all groups began to return toward resting levels. Following exercise, the temperature increased rapidly within the first five minutes of recovery. Subsequently, thigh skin temperatures plateaued at levels significantly higher than resting levels. During the first five minutes of exercise, thigh skin temperatures decreased more in sedentary subjects than in joggers. During recovery, marathoners had the

greatest decrease from the 5 minute post exercise temperature during the first half of recovery. At all other times there were no significant differences between the groups.

Calf Skin Temperature

During exercise, skin temperature increased in all groups (Tables 17 and 18 and Figure 9). Following exercise, there was a significant increase in temperature to a peak at five minutes in the marathoners and joggers while the change in the sedentary group was not significant. During the first half of recovery, temperatures decreased significantly in all groups. During the latter half of recovery, temperatures continued to decrease significantly in the joggers and sedentary group, but not in the marathoners. By one hour after exercise the calf temperatures of the joggers and sedentary group had returned toward their resting levels; however, the marathoners' calf temperatures remained well above their resting level.

Scapula Skin Temperature

With exercise, scapula skin temperature decreased significantly in all groups (Tables 19 and 20 and Figure 10). Marathoners had significantly higher temperatures at ten minutes and at end exercise than did joggers.

Lumbar Skin Temperature

There was no significant change in lumbar skin temperature

with exercise in any group nor was there a significant difference between the groups (Tables 21 and 22 and Figure 11).

Mathematical Formulae: Mean Skin Temperature ($\bar{T}_{sk}$)

Mean Weighted Skin Temperature (3 points), (M_3WST)

During exercise there was no significant difference between the groups in M_3WST (Tables 23 and 24 and Figure 12). However, there were significant increases with exercise in M_3WST in the joggers (R-10M) and sedentary group (R-END). Temperature peaked five minutes post exercise and then fell during the first half of recovery in each group. During the second half of recovery, the M_3WST of the joggers and sedentary group plateaued near resting levels and above resting levels, respectively. The M_3WST of marathoners increased during the second half of recovery to a level well above resting levels at one hour after exercise. There were no significant differences between groups in M_3WST at any time during recovery.

Mean Weighted Skin Temperature (4 points), (M_4WST)

At rest and during exercise there were no significant differences in M_4WST or changes in M_4WST between groups (Tables 25 and 26 and Figure 13). During the first few minutes of recovery, M_4WST peaked in each group. Marathoners subsequently decreased their M_4WST but it remained higher than the resting level throughout recovery. The M_4WST in joggers and sedentary subjects plateaued after the initial peak and remained above resting levels throughout recovery. There were no significant differences between groups in M_4WST during recovery.

When M_3WST and M_4WST are compared (Table 27), significant differences in these calculated mean skin temperatures are apparent. At rest, in marathoners and joggers, M_3WST was higher than M_4WST; during exercise M_3WST was significantly higher than M_4WST in all groups.

Arithmetic Mean 5 Point Skin Temperature (M_5AST)

During exercise there was no significant change in M_5AST in any group (Tables 28 and 29, Figure 14). M_5AST peaked within the first few minutes of recovery and remained above resting levels. There was no significant difference between groups in M_5AST at any time during rest, exercise, or recovery.

Tables 30 and 31 compare M_5AST with M_3WST and M_4WST. M_3WST was lower than M_5AST at rest in the sedentary group, whereas M_4WST was lower than M_5AST at rest in all groups. M_3WST was significantly higher at 5 and 10 minutes of exercise in marathoners. M_4WST was significantly lower than M_5AST at most points during exercise in all groups. During recovery M_3WST was significantly lower than M_5AST from 20 to 60 minutes post exercise in the joggers and from 5 to 60 minutes post exercise in the sedentary group; M_4WST was also significantly lower than M_5AST in the joggers and sedentary group during recovery. Marathoners' M_3WST and M_5AST or M_4WST and M_5AST were not different at any time during recovery.

Arithmetic Mean 7 Point Skin Temperature (M_7AST)

During exercise there was a significant decrease in M_7AST in all groups (Tables 32 and 33, Figure 15). During recovery the

M_7AST increased rapidly in each group and then plateaued well above resting level. There were no significant differences between groups.

At rest, during exercise, and during most of recovery M_3WST and M_4WST were significantly higher than M_7AST in marathoners (Tables 34 to 35). M_3WST was higher than M_7AST during exercise and early recovery in joggers and sedentary subjects. M_4WST was higher than M_7AST only at end exercise and early recovery in the joggers and sedentary group.

Mathematical Formulae: Mean Body Temperature ($\bar{T}_b$)

Mean 5 (Arithmetic) Body Temperature (M_5AT_b)

During exercise M_5AT_b, which is 2/3 T_{re} + 1/3 M_5AST, increased at the end of exercise in each group (Table 36 and 37, Figure 16). During recovery, the M_5AT_b peaked during the first few minutes post exercise and subsequently decreased during the first half of recovery. During the second half of recovery, each group plateaued at a level significantly higher than their resting levels. Except for a greater M_5AT_b at 5M in the sedentary group as compared to the marathoners, there were no significant differences between the groups at rest, during exercise, or during recovery.

Mean 4 (Weighted) Body Temperature (M_4WT_b)

During exercise the M_4WT_b increased at end exercise in the marathoners and joggers (Tables 38 and 39 and Figure 17). During recovery, M_4WT_b peaked at five to 15 minutes post exercise and subsequently decreased, but remained higher than resting values at 60 minutes recovery. During exercise, there

were no significant differences between the groups. The only difference between the groups during recovery was the greater M_4WT_b at 5P and 15P in the marathoners.

Mean 3 (Weighted) Body Temperature (M_3WT_b)

During exercise M_3WT_b increased significantly at ten minutes in the joggers and sedentary group and at end exercise in all groups (Tables 40 and 41 and Figure 18). There were no significant differences between groups during exercise. During recovery, in all groups, M_3WT_b increased to a peak within the first few minutes of exercise, decreased during the first half of recovery, and then plateaued during the second half of the recovery period. Marathoners, when compared with joggers, had a significantly higher M_3WT_b during the first half of recovery and at 50P.

Mathematical Formulae: Heat Content

Mean 5 (Arithmetic) Change in Body Heat Content ($M_5A\Delta S$) and Heat Storage (M_5AS)

$M_5A\Delta S$ was only slightly positive at the end of exercise (Table 42). However, the amount of $M_5A\Delta S$ at end of exercise for marathoners and joggers was markedly greater compared to the sedentary group. From the end of exercise to the first few minutes of recovery, $M_5A\Delta S$ increased significantly in all groups. During the first half of recovery all groups were comparable in the amount of decrease in body heat, and during the second half of recovery all groups maintained their level of body heat.

At the end of exercise M_5AS was only slightly positive, but it increased markedly in the early stages of recovery (Table 43 and Figure 19). There were no significant differences between groups during exercise. After the first 10 minutes of recovery heat storage decreased, but at one hour was still markedly elevated. The only significant difference in heat storage (M_5AS) between the groups was at 60P, with the marathoners having a greater total body heat storage than the sedentary group.

Mean 4 (Weighted) Change in Body Heat Content ($M_4W\Delta S$) and Heat Storage (M_4WS)

$M_4W\Delta S$ during exercise was similar to $M_5A\Delta S$ except marathoners did not have as great an increase at the end of exercise (Table 44). The marked increase of $M_4W\Delta S$ during the first few minutes of recovery was also similar to $M_5A\Delta S$, with the marathoners showing the greatest positive change. During the first half of recovery, all groups decreased in body heat but the sedentary group had much less of a decline than marathoners or joggers. During the second half of recovery $M_4W\Delta S$ changed very little in all groups as did $M_5A\Delta S$.

During exercise and recovery M_4WS was similar to M_5AS (Table 45 and Figure 20). However, M_4WS was not different among the groups at 50P as was M_5AS.

Mean 3 (Weighted) Change in Body Heat Content ($M_3W\Delta S$) and Heat Storage (M_3WS)

By the end of exercise $M_3W\Delta S$ was similar to $M_5A\Delta S$, and $M_4W\Delta S$ except for the sedentary group who showed a slight increase earlier

during exercise (Table 46). From end of exercise to the first few minutes of recovery, all groups expressed a marked increase in $M_3W\Delta S$ with marathoners having the greatest positive change. During the first half of recovery, body heat as calculated by $M_3W\Delta S$ decreased in all groups as it did when calculated by $M_5A\Delta S$. However the sedentary group showed a greater decrease than marathoners or joggers. During the second half of recovery, body heat did not change markedly in any group.

During exercise and recovery M_3WS was nearly identical to M_5AS and M_4WS (Table 47 and Figure 21). However, M_3WS was greater in marathoners than in the sedentary group at 50P and 60P.

Mathematical Formulae: Heat Gradient (H_{grad})

Mean 5 (Arithmetic) Heat Gradient (M_5AH_{grad})

The $M_5\ AH_{grad}$ was not significantly different at any time point when the groups were compared (Table 48). However, the change in M_5AH_{grad} from rest to the end of exercise (R-End) was greater in marathoners than joggers (Table 49).

Mean 4 (Weighted) Heat Gradient (M_4WH_{grad})

At rest, during exercise, and during recovery there were no significant differences in M_4WH_{grad} between the groups (Tables 50 and 51). However, the total change in M_4WH_{grad} was greater in marathoners than in joggers from rest to the end of exercise.

Mean 3 (Weighted) Heat Gradient (M_3WH_{grad})

The M_3WH_{grad} was greater in sedentary subjects than in marathoners at rest, but there was no other significant difference between groups (Tables 52 and 53).

Correlations

T_{sk} and T_{re} with $\dot{V}O_2max$

Tables A and B present those correlation coefficients with significant p-values for correlations between T_{sk} or T_{re} and $\dot{V}O_2max$ for the three groups combined. The most consistent correlation of temperature with $\dot{V}O_2max$ at rest, at each time point during exercise, and at each time point during recovery, was seen in the T_{re} and the calf T_{sk}. The abdomen T_{sk} was fairly consistent at rest, during exercise (except for End), and up to 15 minutes post exercise. No other T_{sk} presented consistent correlations.

T_{sk} and T_{re} with Percent Body Fat

Table C presents those correlation coefficients with significant p-values for correlations between T_{sk} or T_{re} and body fat for the three groups combined. The most consistent correlations (inverse) of temperature with percent body fat were seen in the chest and abdomen T_{sk}. The T_{re} correlations were less consistent. During exercise the forearm and hand T_{sk} presented a consistent correlation which, however, was not the case during recovery. All other T_{sk} did not present consistent correlations and therefore were not considered to be equally related to percent body fat.

Blood Values

Lactate Concentrations

Lactate concentrations from analyses of blood collected at rest, end exercise, and at one hour post exercise in all three groups, increased markedly during exercise and were still considerably elevated at one hour post exercise (see Table D). However, there were no significant differences between groups at end exercise or at either of the resting measurements.

Skinfold Measurements

Table E presents the skinfold thickness measurements taken at seven skin sites prior to exercise on all subjects. Marathoners had significantly lower skinfold thickness at each site.

Metabolic Energy Costs

The energy cost of exercise expressed in watts and/or kcals was greatest in joggers and the sedentary subjects during equal time intervals during exercise (see Table F). However, by the end of exercise, marathoners had the greatest energy cost.

TABLE 1. General characteristics of test subjects; marathoners, joggers, and sedentary group. Asterisk(s) denotes significance of difference between groups. Values are means ± S.D.

TABLE 1

General Data on Subjects

	Marathoners	Joggers	Sedentary	Differences between groups, p-Value (1)
n	16	19	15	
Age, years	36.7±9.0	36.6±9.4	33.3±8.9	
Height, cm	177.7±7.1	179.8±6.3	181.1±5.0	
Total Body Weight, kg	68.2±6.8	76.2±8.8	78.2±10.1	J>M **, S>M **
Body Fat, %	8.7±2.5	14.3±4.7	14.4±5.4	J>M ***, S>M ***
Lean body Weight, kg	62.9±5.4	65.1±7.2	66.6±6.9	
Surface Area, m^2	1.85±0.1	1.95±0.1	1.98±0.1	J>M *, S>M **
Treadmill Time, min	16.2±1.61	13.0±1.03	11.7±1.64	M>J *, M>S *** J>S **

(1) * $p < 0.02$; ** $p < 0.01$; *** $p < 0.001$

TABLE 2. Oxygen consumption at rest, during exercise, and at the end of exercise in each subject group; $\dot{V}O_2$, ml · kg^{-1} · min^{-1}. Values in parentheses equal ($\dot{V}O_2$, ml · min^{-1}). Asterisk(s) denotes significance of difference between groups. Values are means ± S.D.

TABLE 2

Oxygen Consumption

		Exercise			
	Rest	5 Min	10 Min	End	Max
Marathoners	4.5±1.4	21.9±2.8	41.8±3.5	59.8±9.0	60.1±8.1
	(307)	(1494)	(2851)	(4078)	(4099)
Joggers	3.1±1.0	19.8±2.4	36.9±3.8	45.5±6.3	46.1±6.0
	(236)	(1509)	(2812)	(3467)	(3573)
Sedentary	3.2±1.4	19.4±2.7	35.0±4.0	39.9±7.5	40.2±7.7
	(250)	(1517)	(2737)	(3120)	(3144)
p-Value[1]	M>J **		M>J ***	M>J ***	M>J ***
	M>S **	M>S *	M>S ***	M>S **	M>S ***
				J>S *	J>S *

(1) * $p < 0.02$; ** $p < 0.01$; *** $p < 0.001$

FIGURE 1. Graph of rectal temperature (T_{re}), °C response of subject groups versus time.

Where: Δ = marathoners

$\square$ = joggers

o = sedentary groups

Shaded area = the exercise time period

P = minutes post exercise

Nonconnected symbols and the letter E represent the end of exercise time.

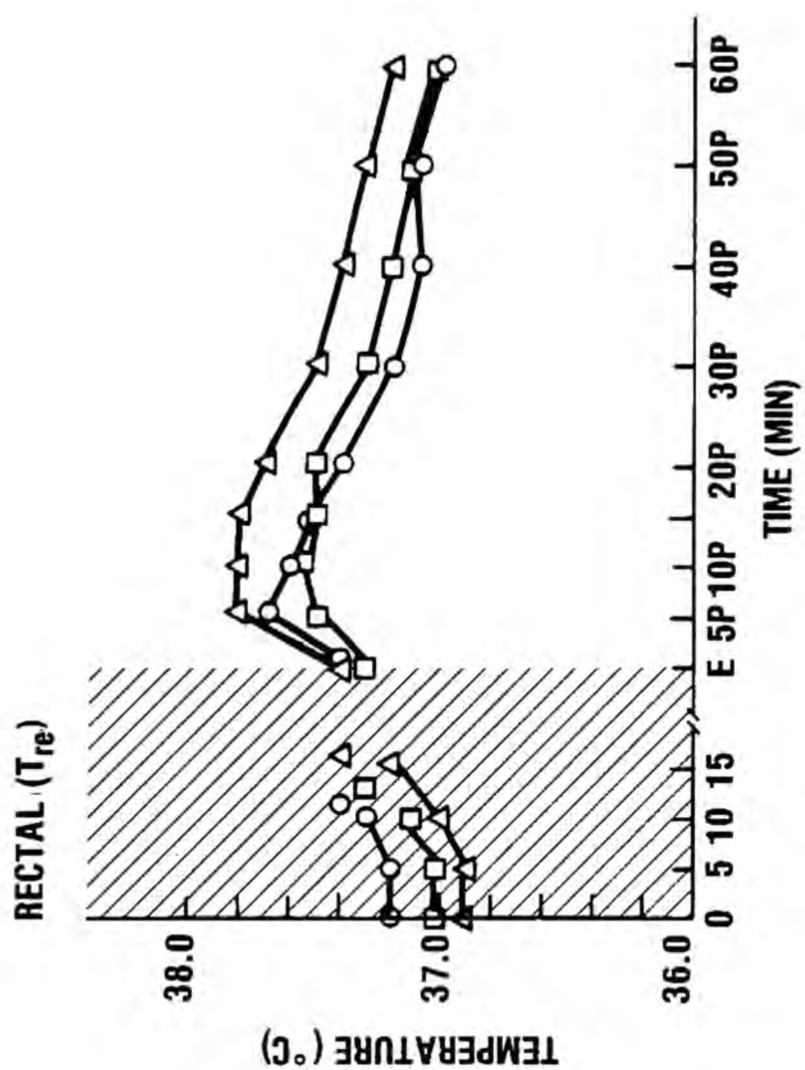

RECTAL (Tre)
TEMPERATURE (°C)
38.0
37.0
36.0
0 5 10 15
E 5P 10P 20P 30P 40P 50P 60P
TIME (MIN)

FIGURE 1

TABLE 3. Rectal temperature (T_{re}), °C of subject groups at rest, during exercise, and during recovery.

Where: M = minutes during exercise

End = the end of exercise

P = minutes post exercise

Asterisk(s) denotes significance of difference between groups.

Values are carried to two decimal point in "rest" and "exercise" T_{re} due to expression of significance at these levels of temperature difference.

Values are means ± S.D.

TABLE 3

Rectal Temperatures (T_{re}), °C

Time	Marathoners	Joggers	Sedentary	Differences between groups p-Value (1)
Rest	36.90±0.15	37.00±0.20	37.15±0.20	S>M ***, S>J **
5M	36.90±0.15	37.00±0.25	37.20±0.20	S>M ***, S>J **
10M	37.00±0.15	37.10±0.25	37.31±0.20	S>M ***, S>J *
End	37.35±0.30	37.25±0.25	37.45±0.20	
5P	37.8±0.3	37.5±0.3	37.7±0.2	M>J **
10P	37.8±0.2	37.6±0.3	37.6±0.2	
15P	37.8±0.2	37.5±0.3	37.5±0.2	M>S ***, M>J **
20P	37.7±0.2	37.5±0.3	37.4±0.2	M>S ***, M>J **
30P	37.5±0.2	37.3±0.5	37.2±0.2	M>S ***, M>J *
40P	37.4±0.2	37.2±0.3	37.1±0.2	M>S **
50P	37.3±0.2	37.1±0.3	37.1±0.2	
60P	37.2±0.2	37.0±0.2	37.0±0.2	

(1) * $p < 0.02$; ** $p < 0.01$; *** $p < 0.001$

TABLE 4. The change in rectal temperature, °C, between time intervals, in each group.

Where: R = rest

M = minutes during exercise

End = the end of exercise

P = minutes post exercise

Asterisk(s) denote significance of change within each group and between the groups.

Values are means ± S.D.

TABLE 4

Change in Rectal Temperatures (T_{re}), °C

Time	Marathoners	Joggers	Sedentary	Differences between groups p-Value (1)
R-5M	0.01±0.07	0.02±0.06	0.03±0.05	
R-10M	0.07±0.12*	0.13±0.10***	0.15±0.09***	S>M *
R-End	0.46±0.24***	0.27±0.20***	0.27±0.14***	M>J ***, M>S ***
(End at)	(16.1 min)	(13.0 min)	(11.7 min)	
End-5P	0.43±0.15***	0.28±0.13***	0.26±0.10***	M>J **, M>S ***
5P-30P	-0.25±0.2***	-0.24±0.23**	-0.49±0.29***	S>J **, S>M *
30P-60P	-0.35±0.11***	-0.28±0.13***	-0.21±0.08***	M>S ***
R-60P	0.28±0.21***	0.07±0.23	-0.17±0.23	

(1) * $p < 0.02$; ** $p < 0.01$; *** $p < 0.001$

FIGURE 2. Graph of relationship of rectal temperature (T_{re}), °C, to oxygen consumption ($\dot{V}O_2$, $ml \cdot kg^{-1} \cdot min^{-1}$) (relative aerobic work), in each group at rest and during exercise.

Where: Δ = marathoners

□ = joggers

o = sedentary group

Percentages = % of $\dot{V}O_2max$

Time = minutes of exercise

Shaded areas = heat accumulation

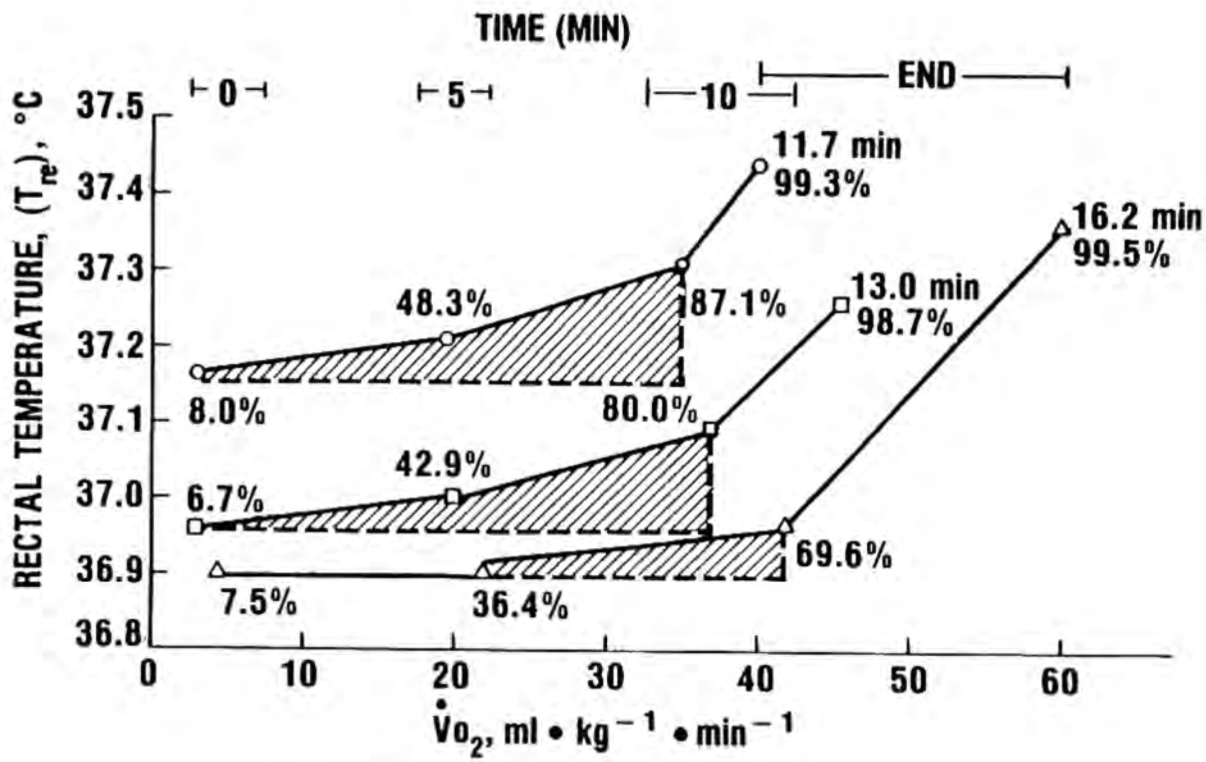

TIME (MIN)
0
5
10
END
RECTAL TEMPERATURE, (T_{re}), °C
37.5
37.4
37.3
37.2
37.1
37.0
36.9
36.8
0
10
20
30
40
50
60
$\dot{V}o_2$, ml • kg^{-1} • min^{-1}
11.7 min
99.3%
13.0 min
98.7%
16.2 min
99.5%
87.1%
80.0%
69.6%
48.3%
42.9%
36.4%
8.0%
6.7%
7.5%

FIGURE 2

TABLE 5. Forehead skin temperatures, °C of subject groups at rest, during exercise, and during recovery.

Where: M = minutes during exercise

End = the end of exercise

P = minutes post exercise

( ) = n; number of subjects evaluated.

Values are means ± S.D.

TABLE 5

Forehead Skin Temperatures, °C

Time	Marathoners	Joggers	Sedentary
Rest	33.0±1.1 (15)	33.0±1.0 (19)	33.3±1.1 (15)
5M	32.8±1.1 (15)	32.8±1.2 (19)	33.3±0.9 (15)
10M	32.8±1.1 (15)	32.8±1.3 (19)	33.3±1.0 (14)
End	32.5±1.8 (15)	32.9±1.3 (19)	33.3±1.1 (15)
5P	34.3±1.6 (16)	34.1±1.3 (19)	34.5±1.3 (15)
10P	34.1±1.5 (16)	34.2±1.1 (17)	34.6±1.0 (15)
15P	33.6±1.6 (16)	33.8±1.1 (19)	34.5±1.1 (15)
20P	33.1±1.6 (16)	33.6±1.0 (19)	34.2±0.8 (15)
30P	32.7±1.6 (16)	33.1±0.7 (19)	33.3±1.2 (15)
40P	32.9±1.7 (16)	33.3±0.7 (19)	33.5±1.2 (15)
50P	33.4±1.6 (16)	33.7±0.6 (19)	33.8±0.8 (15)
60P	33.5±1.5 (16)	33.6±0.8 (18)	34.0±0.2 (15)

TABLE 6. The change in forehead skin temperature, °C between time intervals in each group.

Where: R = rest

M = minutes during exercise

End = the end of exercise

P = minutes post exercise

( ) = n; number of subjects evaluated

Asterisk(s) denotes significance of change within each group.

Values are means ± S.D.

TABLE 6

Change in Forehead Skin Temperatures, °C

Time	Marathoners	Joggers	Sedentary
R-5M	-0.2±1.0 (15)	-0.2±0.5 (19)	0.0±0.7 (15)
R-10M	-0.2±0.1 (15)	-0.2±0.7 (19)	0.1±0.7 (14)
R-End	-0.5±1.2 (15)	-0.1±0.9 (19)	0.1±0.9 (15)
End-5P	1.7±0.8 (15)***	1.1±1.0 (19)***	1.1±0.8 (15)***
5P-30P	-1.6±1.0 (16)***	-1.0±1.3 (14)**	-1.2±1.7 (15)*
30P-60P	0.8±0.6 (16)***	0.6±0.5 (19)**	0.7±1.0 (15)*
R-60P	0.5±1.0 (15)*	0.7±0.9 (18)**	0.7±1.1 (15)*

* $p < 0.02$; ** $p < 0.01$; *** $p < 0.001$

FIGURE 3. Graph of forehead skin temperature, °C response of subject groups versus time.

Where: Δ = marathoners

□ = joggers

o = sedentary group

Shaded area = the exercise time period

P = minutes post exercise

Nonconnected symbols and the letter E represent the end of exercise time.

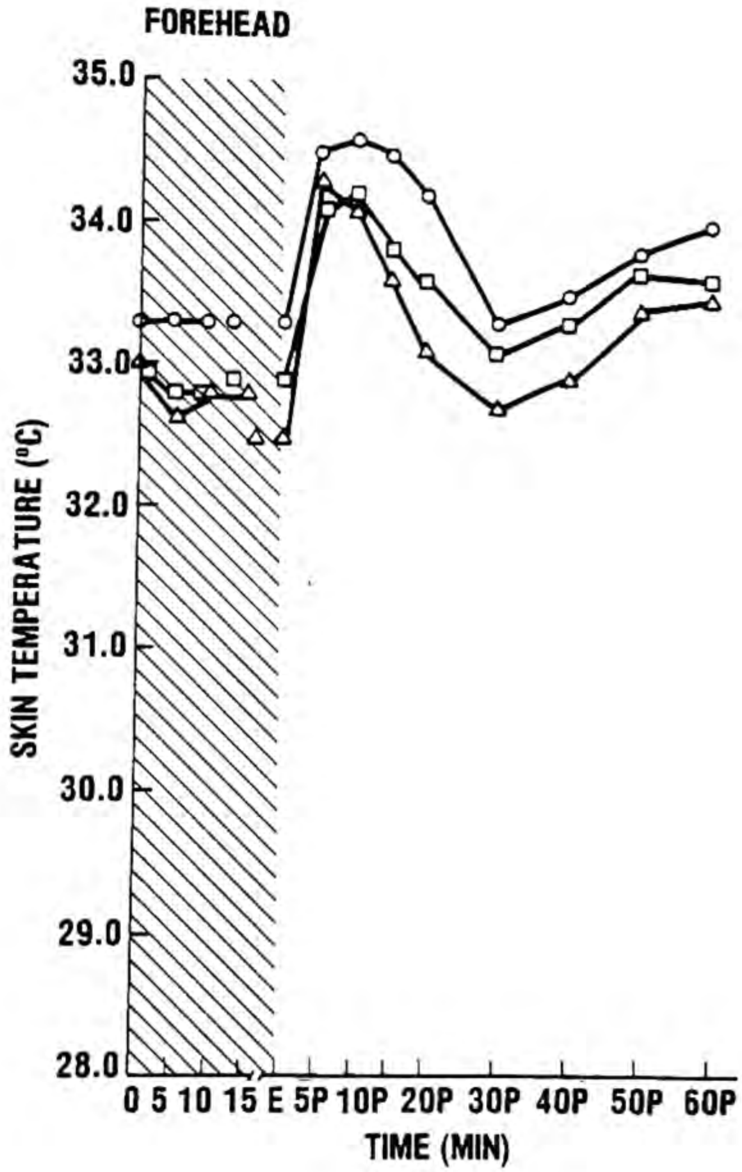

FOREHEAD
35.0
34.0
33.0
32.0
31.0
30.0
29.0
28.0
SKIN TEMPERATURE (°C)
0 5 10 15 E 5P 10P 20P 30P 40P 50P 60P
TIME (MIN)

FIGURE 3

TABLE 7. Chest skin temperatures, °C of subject groups at rest, during exercise, and during recovery.

Where: M = minutes during exercise

End = the end of exercise

P = minutes post exercise

( ) = n; number of subjects evaluated

Asterisk(s) denotes significance of difference between groups.

Values are means ± S.D.

TABLE 7

Chest Skin Temperatures, °C

Time	Marathoners	Joggers	Sedentary	Differences between groups, p-Value (1)
Rest	31.7±1.0 (15)	31.5±1.4 (17)	31.1±0.9 (15)	
5M	31.8±1.1 (14)	31.7±1.3 (17)	31.3±0.8 (15)	
10M	31.6±1.1 (14)	31.6±1.4 (17)	31.3±1.0 (14)	
End	31.0±1.4 (14)	31.3±1.7 (16)	31.0±1.1 (15)	
5P	32.7±2.2 (14)	31.9±1.9 (18)	32.0±1.3 (15)	
10P	32.3±1.2 (15)	31.8±1.6 (16)	32.1±1.2 (15)	
15P	32.1±1.1 (15)	31.8±1.2 (18)	32.0±1.0 (15)	
20P	31.7±1.3 (15)	31.5±1.3 (18)	31.8±0.9 (15)	
30P	31.8±1.1 (13)	31.4±1.1 (18)	31.4±0.8 (15)	
40P	32.1±1.3 (14)	31.6±1.2 (18)	31.6±0.8 (15)	
50P	32.4±1.3 (16)	31.7±1.0 (18)	31.5±0.7 (15)	M>S *
60P	32.5±1.2 (15)	31.5±1.9 (17)	31.6±0.8 (15)	

(1) * $p < 0.02$

TABLE 8. The change in chest skin temperature, °C between time intervals, in each group.

Where: R = rest

M = minutes during exercise

End = the end of exercise

P = minutes post exercise

( ) = n; number of subjects evaluated

Asterisk(s) denote significance of change within each group and significance of difference between groups.

Values are means ± S.D.

TABLE 8

Change in Chest Skin Temperatures, °C

Time	Marathoners	Joggers	Sedentary	Differences between groups, p-Value (1)
R-5M	0.1±0.9 (14)	0.2±0.7 (17)	0.2±0.6 (18)	
R-10M	-0.2±0.7 (14)	0.1±0.8 (17)	0.0±0.7 (14)	
R-End	-0.8±1.0 (14)	-0.2±1.0 (16)	-0.1±0.7 (15)	
End-5P	1.8±1.4 (13)***	0.7±0.8 (16)**	1.0±1.2 (15)**	M>J *
5P-30P	-1.2±1.5 (13)***	-0.5±2.1 (18)	-0.6±1.3 (15)	
30P-60P	0.5±0.6 (13)	0.2±1.1 (17)	0.2±0.6 (15)	
R-60P	0.7±1.2 (15)*	0.1±1.9 (16)	0.5±1.3 (15)	

(1) * $p < 0.02$; ** $p < 0.01$; *** $p < 0.001$

FIGURE 4. Graph of chest skin temperature, °C response of subject groups versus time.

Where: Δ = marathoners

□ = joggers

o = sedentary group

Shaded area = the exercise time period

P = minutes post exercise

Nonconnected symbols and the letter E represent the end of exercise time.

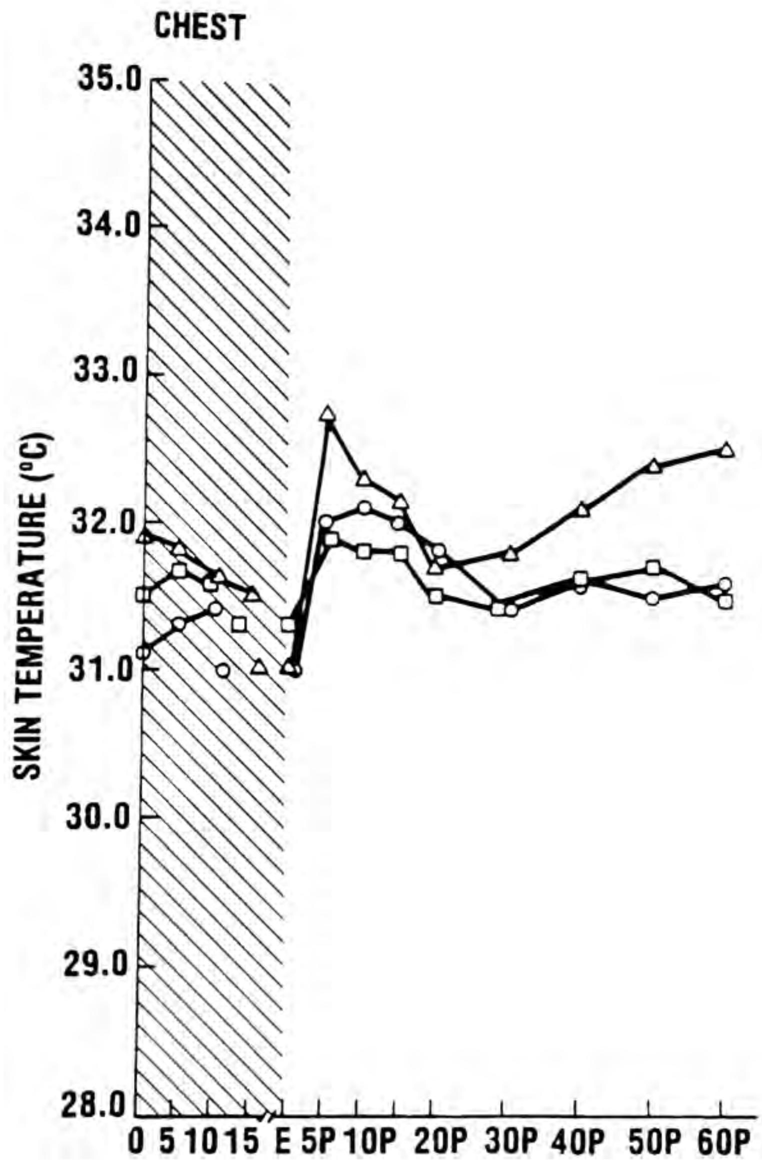

CHEST
35.0
34.0
33.0
32.0
31.0
30.0
29.0
28.0
SKIN TEMPERATURE (°C)
0 5 10 15 E 5P 10P 20P 30P 40P 50P 60P

FIGURE 4

TABLE 9. Abdomen skin temperatures, °C of subject groups at rest, during exercise, and during recovery.

Where: M = minutes during exercise

End = the end of exercise

P = minutes post exercise

( ) = n; number of subjects evaluated

Asterisk(s) denotes significance of difference between groups.

Values are means ± S.D.

TABLE 9

Abdomen Skin Temperatures, °C

Time	Marathoners	Joggers	Sedentary	Differences between groups, p-Value (1)
Rest	31.8±0.7 (16)	31.0±1.0 (19)	31.1±1.4 (15)	M>J **
5M	31.7±0.9 (16)	30.6±1.0 (19)	30.8±1.4 (15)	M>J ***
10M	31.5±1.0 (16)	30.2±1.1 (19)	30.4±1.4 (13)	M>J ***, M>S *
End	30.0±1.3 (16)	29.7±1.1 (17)	30.0±1.3 (14)	
5P	31.4±1.6 (16)	29.9±1.1 (18)	30.7±1.3 (15)	M>J **
10P	31.2±1.7 (16)	30.2±1.6 (16)	30.6±1.6 (15)	
15P	30.8±1.8 (16)	29.6±1.8 (18)	30.5±1.4 (15)	
20P	30.5±1.9 (16)	29.8±1.6 (18)	30.5±1.4 (15)	
30P	30.4±2.1 (15)	30.1±1.6 (18)	30.5±1.4 (14)	
40P	30.6±2.2 (15)	30.4±1.6 (18)	30.8±1.3 (15)	
50P	31.0±2.0 (16)	30.9±1.5 (18)	31.1±1.3 (15)	
60P	31.4±2.3 (16)	31.0±1.7 (17)	31.3±1.1 (15)	

(1) * $p < 0.02$; ** $p < 0.01$; *** $p < 0.001$

TABLE 10. The change in abdomen skin temperature, °C between time intervals in each group.

Where: R = rest

M = minutes during exercise

End = the end of exercise

P = minutes post exercise

( ) = n; number of subjects evaluated

Asterisk(s) denote significance of change within each group and significance of difference between groups.

Values are means ± S.D.

TABLE 10

Change in Abdomen Temperatures, °C

Time	Marathoners	Joggers	Sedentary	Differences between groups, p-Value (1)
R-5M	-0.1±0.5 (16)	-0.4±0.6 (19)*	-0.3±0.7 (15)*	
R-10M	-0.3±0.7 (16)	-0.8±0.8 (19)***	-0.8±0.6 (13)***	J>M *, S>M *
R-End	-1.8±1.1 (16)***	-1.3±1.0 (17)***	-1.0±0.6 (14)***	
End-5P	1.4±1.3 (16)***	0.3±0.7 (17)	0.7±0.8 (14)**	M>J *
5P-30P	-1.0±2.1 (15)*	0.2±1.7 (18)	-0.2±1.3 (15)	
30P-60P	0.9±1.0 (15)**	0.9±1.1 (17)**	0.8±0.7 (15)***	
R-60P	0.4±2.0 (16)	0.0±1.5 (17)	0.2±0.8 (15)	

(1) * $p < 0.02$; ** $p < 0.01$; *** $p < 0.001$

FIGURE 5. Graph of abdomen skin temperature, °C response of subject groups versus time.

Where: Δ = marathoners

□ = joggers

o = sedentary group

Shaded area = the exercise time period

P = minutes post exercise

Nonconnected symbols and the letter E represent the end of exercise time.

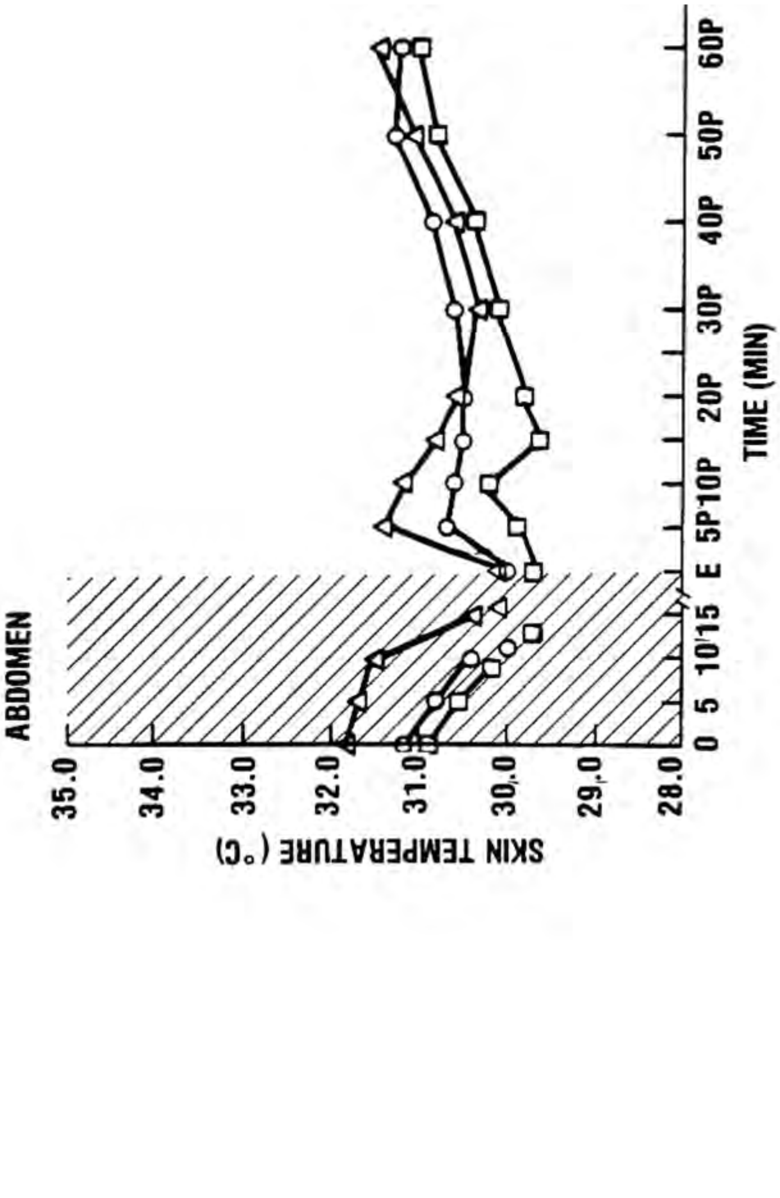

ABDOMEN
SKIN TEMPERATURE (°C)
35.0
34.0
33.0
32.0
31.0
30.0
29.0
28.0
0 5 10 15 E 5P 10P 20P 30P 40P 50P 60P
TIME (MIN)

FIGURE 5

TABLE 11. Forearm skin temperature, °C of subject groups at rest, during exercise, and during recovery.

Where: M = minutes during exercise

End = the end of exercise

P = minutes post exercise

( ) = n; number of subjects evaluated

Asterisk(s) denotes significance of difference between groups.

Values are means ± S.D.

TABLE 11

Forearm Skin Temperatures, °C

Time	Marathoners	Joggers	Sedentary	Differences between groups, p-Value (1)
Rest	29.7±1.2 (16)	30.4±0.8 (19)	30.6±0.8 (15)	
5M	29.2±1.3 (16)	29.8±0.9 (19)	30.1±0.9 (15)	
10M	28.9±1.4 (16)	29.5±1.2 (19)	29.6±0.8 (14)	
End	28.1±1.6 (16)	29.2±1.4 (19)	28.9±1.1 (15)	
5P	29.5±2.4 (16)	30.0±1.5 (19)	30.5±1.1 (15)	
10P	29.4±2.8 (16)	30.2±1.3 (17)	30.6±1.5 (15)	
15P	29.5±2.1 (16)	30.3±1.5 (18)	31.1±1.2 (15)	S>M *
20P	29.5±2.2 (16)	30.7±1.4 (18)	31.3±1.1 (15)	S>M **
30P	30.0±2.3 (16)	31.4±1.3 (18)	31.2±1.2 (15)	
40P	30.7±2.4 (16)	32.1±1.2 (18)	31.8±1.2 (14)	
50P	31.0±2.4 (16)	32.4±1.0 (18)	32.1±1.0 (15)	
60P	30.9±2.3 (16)	32.4±1.0 (17)	32.1±1.2 (15)	

(1) * $p < 0.02$; ** $p < 0.01$

TABLE 12. The change in forearm skin temperature, °C between time intervals in each group.

Where: R = rest

M = minutes during exercise

End = the end of exercise

P = minutes post exercise

( ) = n; number of subjects evaluated.

Asterisk(s) denotes significance of change within each group.

Values are means ± S.D.

TABLE 12

Change in Forearm Skin Temperatures, °C

Time	Marathoners	Joggers	Sedentary
R-5M	-0.5±0.6 (16)**	-0.6±0.7 (19)**	-0.5±0.5 (15)***
R-10M	-0.9±0.7 (16)***	-0.9±0.9 (19)***	-1.1±0.6 (14)***
R-End	-1.7±1.2 (16)***	-1.2±1.3 (19)***	-1.7±1.0 (15)***
End-5P	1.4±1.3 (16)***	0.8±1.4 (19)*	1.6±1.2 (15)***
5P-30P	0.5±1.7 (16)	1.3±2.0 (18)	0.6±1.6 (15)
30P-60P	0.9±1.1 (16)*	0.9±0.8 (17)***	1.0±0.9 (15)***
R-60P	1.2±1.7 (16)*	1.9±1.0 (17)***	1.5±0.8 (15)***

* $p < 0.02$; ** $p < 0.01$; *** $p < 0.001$

FIGURE 6. Graph of forearm skin temperature, °C response of subject groups versus time.

Where: Δ = marathoners

□ = joggers

o = sedentary group

Shaded area = the exercise time period

P = minutes post exercise

Nonconnected symbols and the letter E represent the end of exercise time.

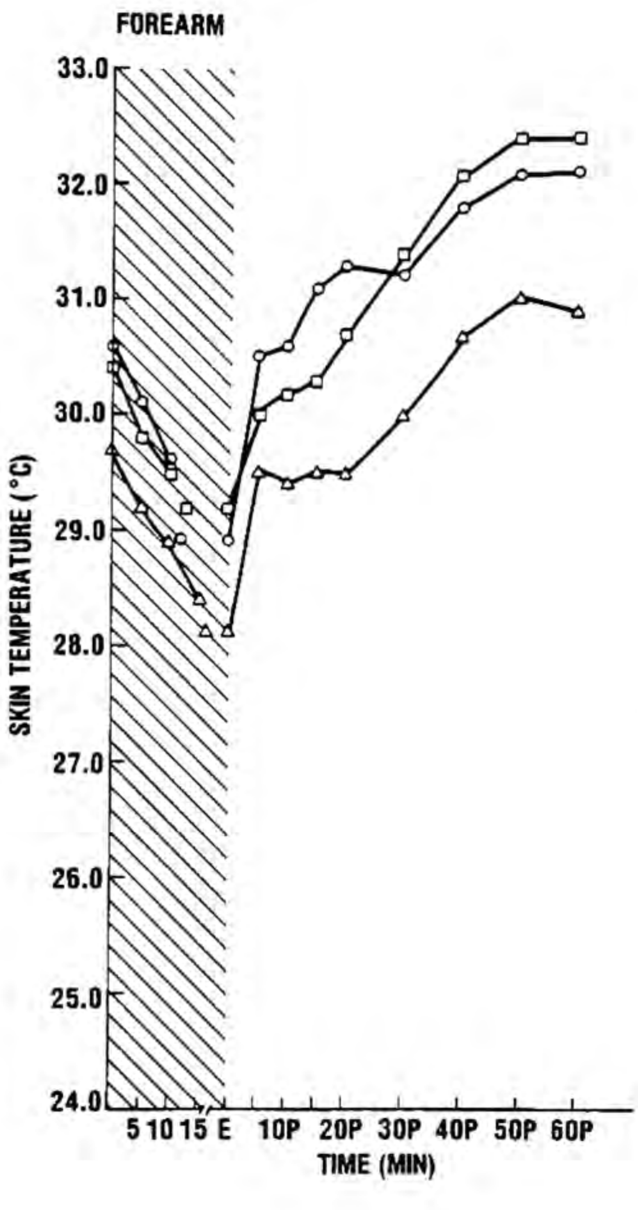

FOREARM
SKIN TEMPERATURE (°C)
33.0
32.0
31.0
30.0
29.0
28.0
27.0
26.0
25.0
24.0
5 10 15 E
10P 20P 30P 40P 50P 60P
TIME (MIN)

FIGURE 6

TABLE 13. Hand skin temperature, °C of subject groups at rest, during exercise, and during recovery.

Where: M = minutes during exercise

End = the end of exercise

P = minutes post exercise

( ) = n; number of subjects evaluated

Asterisk(s) denotes significance of difference between groups.

Values are means ± S.D.

TABLE 13

Hand Skin Temperatures, °C

Time	Marathoners	Joggers	Sedentary	Differences between groups, p-Value [1]
Rest	26.4±1.3 (15)	28.0±1.6 (19)	28.3±1.6 (14)	J>M **, S>M **
5M	26.0±1.2 (15)	27.4±1.6 (19)	27.4±1.1 (14)	J>M **, S>M **
10M	25.7±1.2 (15)	27.2±1.8 (19)	26.7±1.0 (12)	J>M *
End	25.0±1.3 (14)	26.9±1.7 (17)	26.4±0.9 (15)	J>M **, S>M **
5P	26.4±2.9 (15)	26.9±2.0 (19)	26.6±1.3 (14)	
10P	28.1±2.8 (15)	29.0±2.0 (17)	28.7±2.1 (14)	
15P	29.4±2.9 (15)	30.3±2.1 (19)	30.2±2.2 (14)	
20P	30.0±2.3 (15)	31.0±1.7 (19)	30.9±2.0 (14)	
30P	30.6±2.4 (15)	31.3±1.3 (19)	31.1±1.7 (14)	
40P	30.7±2.7 (15)	31.5±1.4 (19)	31.3±1.6 (14)	
50P	30.7±2.6 (15)	31.3±1.5 (19)	31.4±1.7 (14)	
60P	30.7±2.5 (15)	31.1±1.4 (18)	31.4±1.6 (14)	

(1) * $p < 0.02$; ** $p < 0.01$

TABLE 14. The change in hand skin temperature, °C between time intervals in each group.

Where: R = rest

M = minutes during exercise

End = the end of exercise

P = minutes post exercise

( ) = n; number of subjects evaluated

Asterisk(s) denote significance of change within each group and significance of difference between groups.

Values are means ± S.D.

TABLE 14

Change in Hand Skin Temperatures, °C

Time	Marathoners	Joggers	Sedentary	Differences between groups, p-Value (1)
R-5M	-0.5±0.3 (15)***	-0.5±0.7 (19)**	-0.9±0.7 (14)***	
R-10M	-0.7±0.5 (15)***	-0.8±0.9 (19)***	-1.5±1.0 (12)***	S>M *
R-End	-1.3±0.7 (14)***	-1.2±1.0 (17)***	-1.8±1.2 (13)***	
End-5P	1.3±3.0 (14)	0.0±0.6 (17)	0.2±0.9 (13)	
5P-30P	4.3±3.5 (15)***	4.4±1.9 (19)***	4.5±1.9 (14)***	
30P-60P	0.1±1.1 (15)	0.2±0.6 (18)	0.4±1.0 (14)	
R-60P	4.2±1.9 (15)***	3.1±1.7 (18)***	3.1±1.6 (14)***	

(1) * $p < 0.02$; ** $p < 0.01$; *** $p < 0.001$

FIGURE 7. Graph of hand skin temperature, °C response of subject groups versus time.

Where: Δ = marathoners

□ = joggers

o = sedentary group

Shaded area = the exercise time period

P = minutes post exercise

Nonconnected symbols and the letter E represent the end of exercise.

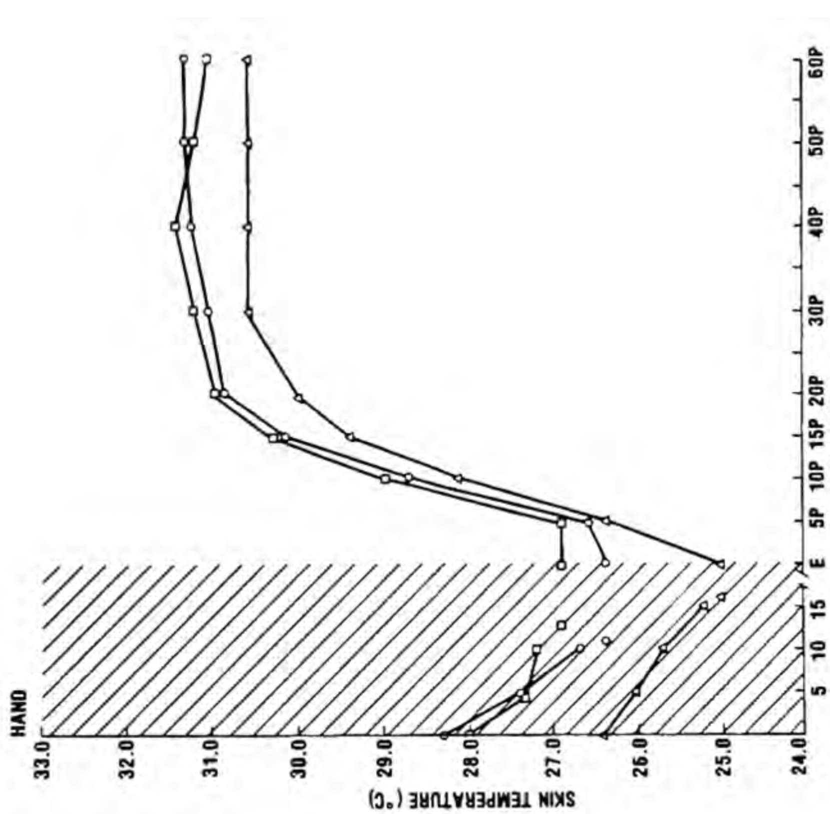

HAND
SKIN TEMPERATURE (°C)
33.0
32.0
31.0
30.0
29.0
28.0
27.0
26.0
25.0
24.0
5
10
15
E
5P
10P
15P
20P
30P
40P
50P
60P
TIME (MIN)

FIGURE 7

TABLE 15. Thigh skin temperature, °C of subject groups at rest, during exercise, and during recovery.

Where: M = minutes during exercise

End = the end of exercise

P = minutes post exercise

( ) = n; number of subjects evaluated

Values are means ± S.D.

TABLE 15

Thigh Skin Temperatures, °C

Time	Marathoners	Joggers	Sedentary
Rest	30.4±1.7 (16)	30.1±1.4 (19)	30.5±0.9 (15)
5M	29.8±1.7 (16)	29.7±1.3 (19)	29.6±1.0 (15)
10M	30.0±1.9 (16)	29.6±1.2 (18)	29.5±1.5 (14)
End	30.4±2.4 (16)	30.2±1.5 (18)	29.9±1.5 (15)
5P	32.7±1.6 (15)	31.7±1.2 (19)	31.6±1.2 (15)
10P	32.8±1.8 (16)	32.1±1.0 (17)	32.0±1.2 (15)
15P	32.5±1.7 (16)	32.0±1.3 (19)	32.1±1.2 (15)
20P	32.4±1.9 (16)	31.9±1.2 (19)	32.2±1.1 (15)
30P	32.1±1.8 (16)	32.1±1.2 (19)	32.0±1.1 (15)
40P	32.1±1.7 (16)	32.1±1.1 (18)	32.2±0.8 (15)
50P	32.2±1.4 (16)	32.0±1.4 (19)	32.3±1.1 (15)
60P	32.3±1.5 (16)	32.3±1.3 (18)	32.2±1.1 (15)

TABLE 16. The change in thigh skin temperature, °C between time intervals in each group.

Where: R = rest

M = minutes during exercise

End = the end of exercise

P = minutes post exercise

( ) = n; number of subjects evaluated

Asterisk(s) denote significance of change within each group and significance of difference between groups.

Values are means ± S.D.

TABLE 16

Change in Thigh Skin Temperatures, °C

Time	Marathoners	Joggers	Sedentary	Differences between groups, p-Value (1)
R-5M	-0.6±0.7 (16)**	-0.3±0.8 (19)	-1.0±0.7 (15)***	S>J **
R-10M	-0.4±0.9 (16)	-0.4±0.8 (18)	-1.1±1.2 (14)**	
R-End	-0.1±1.3 (16)	-0.2±0.9 (18)	-0.7±1.1 (15)	
End-5P	2.7±1.0 (15)***	1.5±0.9 (18)***	1.8±1.4 (15)***	M>J **
5P-30P	-0.9±1.2 (15)**	0.4±1.3 (19)	0.4±1.2 (15)	M>J **, M>S **
30P-60P	0.2±1.1 (16)	0.2±0.9 (18)	0.2±0.7 (15)	
R-60	1.9±1.1 (16)***	2.2±1.5 (18)***	1.7±1.1 (15)***	

(1) * $p < 0.02$; ** $p < 0.01$; *** $p < 0.001$

FIGURE 8. Graph of thigh skin temperature, °C response of subject groups versus time.

Where: Δ = marathoners

□ = joggers

o = sedentary group

Shaded area = the exercise time period

P = minutes post exercise

Nonconnected symbols and the letter E represent the end of exercise time.

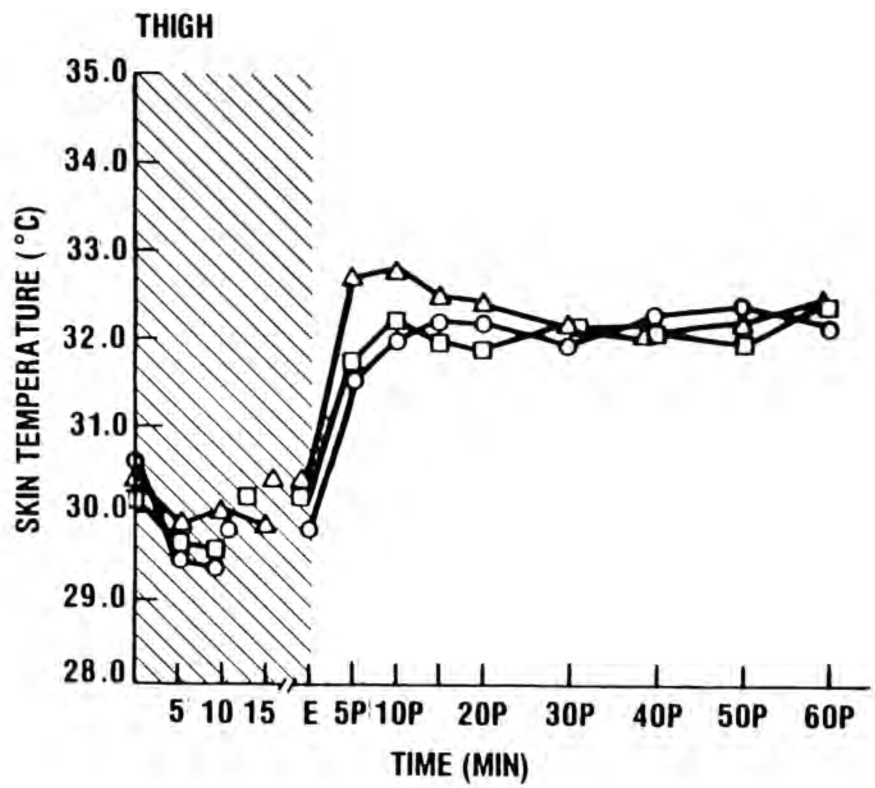

THIGH
SKIN TEMPERATURE (°C)
35.0
34.0
33.0
32.0
31.0
30.0
29.0
28.0
5 10 15 E 5P 10P 20P 30P 40P 50P 60P
TIME (MIN)

FIGURE 8

TABLE 17. Calf skin temperature, °C of subject groups at rest, during exercise, and during recovery.

Where: M = minutes during exercise

End = the end of exercise

P = minutes post exercise

( ) = n; number of subjects evaluated

Asterisk(s) denotes significance of difference between groups.

Values are means ± S.D.

TABLE 17

Calf Skin Temperatures, °C

Time	Marathoners	Joggers	Sedentary
Rest	31.0±1.5 (16)	30.4±1.2 (19)	30.6±1.0 (15)
5M	31.3±1.5 (16)	30.8±1.4 (19)	31.1±1.4 (15)
10M	32.1±1.7 (16)	31.5±1.6 (17)	31.8±1.6 (14)
End	33.0±2.0 (16)	32.1±1.9 (17)	32.2±1.6 (15)
5P	34.0±1.9 (15)	33.2±1.5 (15)	32.8±1.9 (15)
10P	34.0±1.9 (16)	33.0±1.1 (14)	32.7±1.4 (15)
15P	33.7±1.9 (16)	32.6±1.1 (16)	32.2±1.5 (15)
20P	33.2±2.2 (16)	32.2±1.2 (16)	31.9±1.8 (15)
30P	32.7±2.1 (16)	31.7±1.4 (16)	31.8±1.2 (14)
40P	32.5±2.3 (16)	31.5±1.4 (16)	31.6±1.3 (14)
50P	32.6±2.3 (16)	31.4±1.5 (16)	31.6±1.6 (14)
60P	32.4±2.8 (16)	31.3±1.5 (15)	31.1±1.5 (14)

TABLE 18. The change in calf skin temperature, °C between time intervals in each group.

Where: R = rest

M = minutes during exercise

End = the end of exercise

P = minutes post exercise

( ) = n; number of subjects evaluated

Asterisk(s) denotes significance of change within each group.

Values are means ± S.D.

TABLE 18

Change in Calf Skin Temperatures, °C

Time	Marathoners	Joggers	Sedentary
R-5M	0.3±1.2 (16)	0.3±0.8 (19)	0.5±0.6 (15)**
R-10M	1.1±1.5 (16)*	1.1±1.0 (17)***	1.1±0.8 (14)***
R-End	2.0±2.0 (16)***	1.7±1.4 (17)***	1.6±0.8 (13)***
End-5P	0.9±1.2 (15)**	1.3±1.6 (15)**	0.6±1.3 (15)
5P-30P	-1.5±0.7 (15)***	-1.4±1.3 (15)**	-1.0±1.1 (14)**
30P-60P	-0.3±1.4 (16)	-0.5±0.8 (15)*	-0.7±0.8 (15)**
R-60P	1.4±2.1 (16)*	0.9±2.0 (15)	0.4±1.2 (14)

* $p < 0.02$; ** $p < 0.01$; *** $p < 0.001$

FIGURE 9. Graph of calf skin temperature, °C response of subject groups versus time.

Where: Δ = marathoners

□ = joggers

o = sedentary group

Shaded area = the exercise time period

P = minutes post exercise

Nonconnected symbols and the letter E represent the end of exercise time.

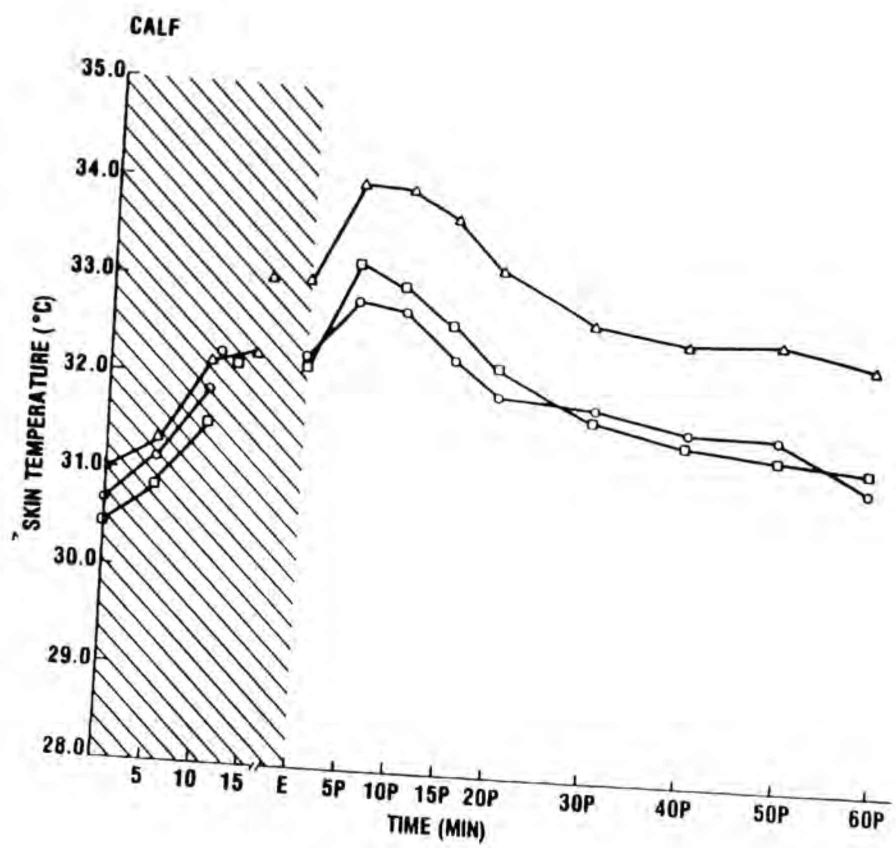

CALF
SKIN TEMPERATURE (°C)
35.0
34.0
33.0
32.0
31.0
30.0
29.0
28.0
5
10
15
E
5P
10P
15P
20P
30P
40P
50P
60P
TIME (MIN)

FIGURE 9

TABLE 19. Scapula skin temperature, °C of subject groups at rest and during exercise.

Where: M = minutes during exercise

End = the end of exercise

( ) = n; number of subjects evaluated

Asterisk(s) denotes significance of difference between groups.

Values are means ± S.D.

TABLE 19

Scapula Skin Temperatures, °C

Time	Marathoners	Joggers	Sedentary	Differences between groups, p-Value (1)
Rest	33.1±1.3 (15)	32.6±0.6 (18)	32.8±1.0 (15)	
5M	32.8±1.2 (15)	32.1±0.5 (17)	32.5±1.0 (15)	
10M	32.8±1.1 (15)	31.9±0.5 (18)	32.4±0.9 (14)	M>J *
End	32.6±1.3 (15)	31.7±1.2 (19)	32.1±1.0 (15)	M>J *

(1) * $p < 0.02$

Note: Scapula skin temperature sensor was confined between the chair and the body during recovery; no values are presented.

TABLE 20. The change in scapula skin temperature, °C between time intervals in each group.

Where: R = rest

M = minutes during exercise

End = the end of exercise

( ) = n; number of subjects evaluated

Asterisk(s) denotes significance of change within each group.

Values are means ± S.D.

TABLE 20

Change in Scapula Skin Temperatures, °C

Time	Marathoners	Joggers	Sedentary
R-5M	-0.4±0.3 (15)***	-0.5±0.4 (17)***	-0.3±0.4 (15)*
R-10M	-0.4±0.3 (15)***	-0.6±0.4 (18)***	-0.4±0.5 (14)**
R-End	-0.5±0.6 (15)**	-0.7±0.5 (18)***	-0.7±0.6 (15)***

* $p < 0.02$; ** $p < 0.01$; *** $p < 0.001$

FIGURE 10. Graph of scapula skin temperature, °C response of subject groups versus time.

Where: Δ = marathoners

□ = joggers

o = sedentary group

Nonconnected symbols and the letter E represent the end of exercise time.

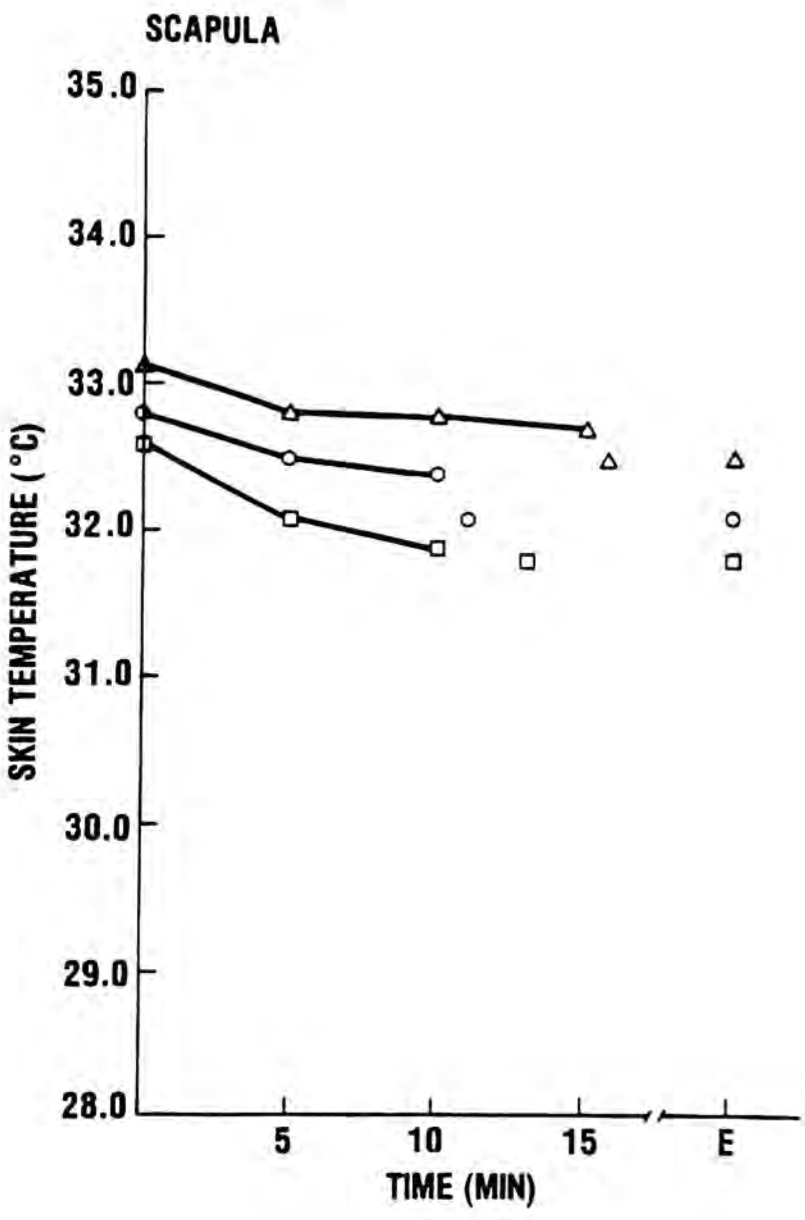

SCAPULA
35.0
34.0
33.0
32.0
31.0
30.0
29.0
28.0
SKIN TEMPERATURE (°C)
5
10
15
E
TIME (MIN)

FIGURE 10

TABLE 21. Lumbar skin temperature, °C of subject groups at rest and during exercise.

Where: M = minutes during exercise

End = the end of exercise

( ) = n; number of subjects evaluated

Values are means ± S.D.

TABLE 21

Lumbar Skin Temperatures, °C

Time	Marathoners	Joggers	Sedentary
Rest	31.8±1.4 (15)	31.6±0.7 (19)	31.6±0.9 (15)
5M	31.7±1.3 (15)	31.4±0.7 (19)	31.5±1.0 (15)
10M	32.0±1.1 (15)	31.4±0.7 (19)	31.7±1.0 (14)
End	32.0±1.3 (15)	30.2±1.5 (18)	29.9±1.5 (15)

Note: Lumbar skin temperature sensor was confined between the chair and the body during recovery; no values are presented.

TABLE 22. The change in lumbar skin temperature, °C between time intervals in each group.

Where: R = rest

M = minutes during exercise

End = the end of exercise

( ) = n; number of subjects evaluated

Values are means ± S.D.

TABLE 22

Change in Lumbar Skin Temperatures, °C

Time	Marathoners	Joggers	Sedentary
R-5M	-0.1±0.4 (15)	-0.2±0.5 (19)	-0.1±0.5 (15)
R-10M	0.2±0.6 (15)	-0.2±0.7 (19)	0.0±0.7 (14)
R-End	0.1±0.8 (15)	0.1±0.9 (19)	-0.1±0.7 (15)

FIGURE 11. Graph of lumbar skin temperature, °C response of subject groups versus time.

Where: Δ = marathoners

□ = joggers

o = sedentary group

Nonconnected symbols and the letter E represent the end of exercise time.

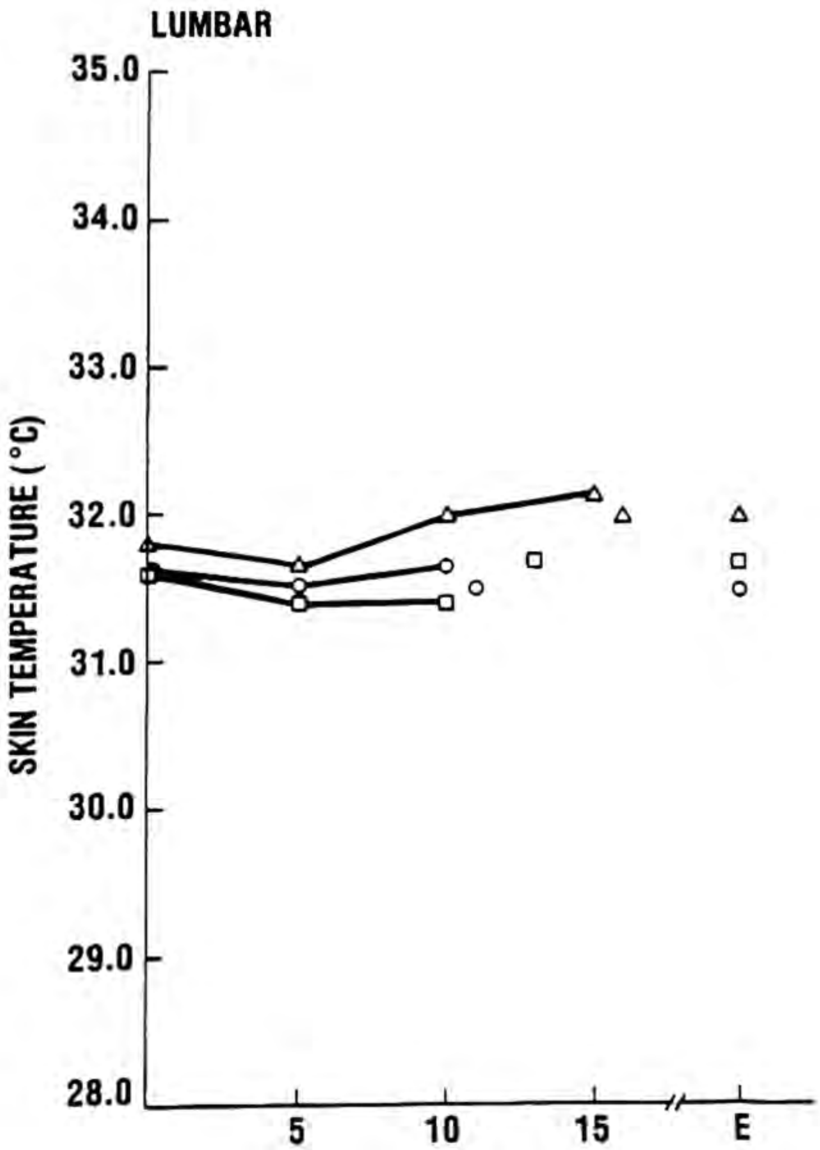

LUMBAR
35.0
34.0
33.0
32.0
31.0
30.0
29.0
28.0
SKIN TEMPERATURE (°C)
5
10
15
E

FIGURE 11

TABLE 23. Mean weighted skin temperature (3 points), M_3WST, °C of subject groups at rest, during exercise, and during recovery.

Where: M = minutes during exercise

End = the end of exercise

P = minutes post exercise

( ) = n; number of subjects evaluated

Values are means ± S.D.

TABLE 23

Mean Weighted Skin Temperature (3 points), (M_3WST), °C

Time	Marathoners	Joggers	Sedentary
Rest	31.2±0.9 (15)	31.0±0.9 (17)	30.9±0.5 (15)
5M	31.2±0.8 (14)	31.1±0.9 (17)	31.1±0.6 (15)
10M	31.4±0.9 (14)	31.2±0.9 (16)	31.2±0.6 (14)
End	31.3±1.0 (14)	31.3±0.9 (15)	31.2±0.7 (15)
5P	32.8±1.3 (13)	32.0±1.0 (14)	32.1±1.0 (15)
10P	32.4±1.1 (15)	31.8±0.6 (13)	32.1±0.9 (15)
15P	32.2±1.1 (15)	31.6±0.6 (14)	31.9±0.7 (15)
20P	31.9±1.2 (15)	31.4±0.7 (14)	31.8±0.8 (15)
30P	31.7±1.0 (13)	31.4±0.8 (14)	31.5±0.5 (14)
40P	32.0±1.3 (14)	31.5±0.8 (14)	31.6±0.5 (13)
50P	32.2±1.2 (15)	31.5±0.9 (14)	31.6±0.6 (14)
60P	32.2±1.4 (15)	31.3±1.3 (13)	31.5±0.6 (14)

TABLE 24. The change in mean weighted skin temperature (3 points), (M_3WST), °C between time intervals in each group.

Where: R = rest

M = minutes during exercise

End = the end of exercise

P = minutes post exercise

( ) = n; number of subjects evaluated

Asterisk(s) denotes significance of change within each group.

Values are means ± S.D.

TABLE 24

Changes in Mean Weighted Skin Temperature (3 points), (M_3WST), °C

Time	Marathoners	Joggers	Sedentary
R-5M	0.1±0.5 (14)	0.1±0.4 (17)	0.2±0.1 (15)
R-10M	0.2±0.6 (14)	0.3±0.5 (16)*	0.3±0.7 (14)
R-End	0.2±0.7 (14)	0.4±0.7 (15)	0.3±0.4 (15)*
R-60P	0.9±1.0 (15)**	0.7±1.4 (12)	0.6±0.3 (14)**
End-5P	1.4±0.8 (13)**	0.8±0.5 (13)***	0.9±0.8 (15)**

* $p < 0.02$; ** $p < 0.01$; *** $p < 0.001$

FIGURE 12. Graph of mean weighted skin temperature (3 points), °C response of subject groups versus time.

Where: Δ = marathoners

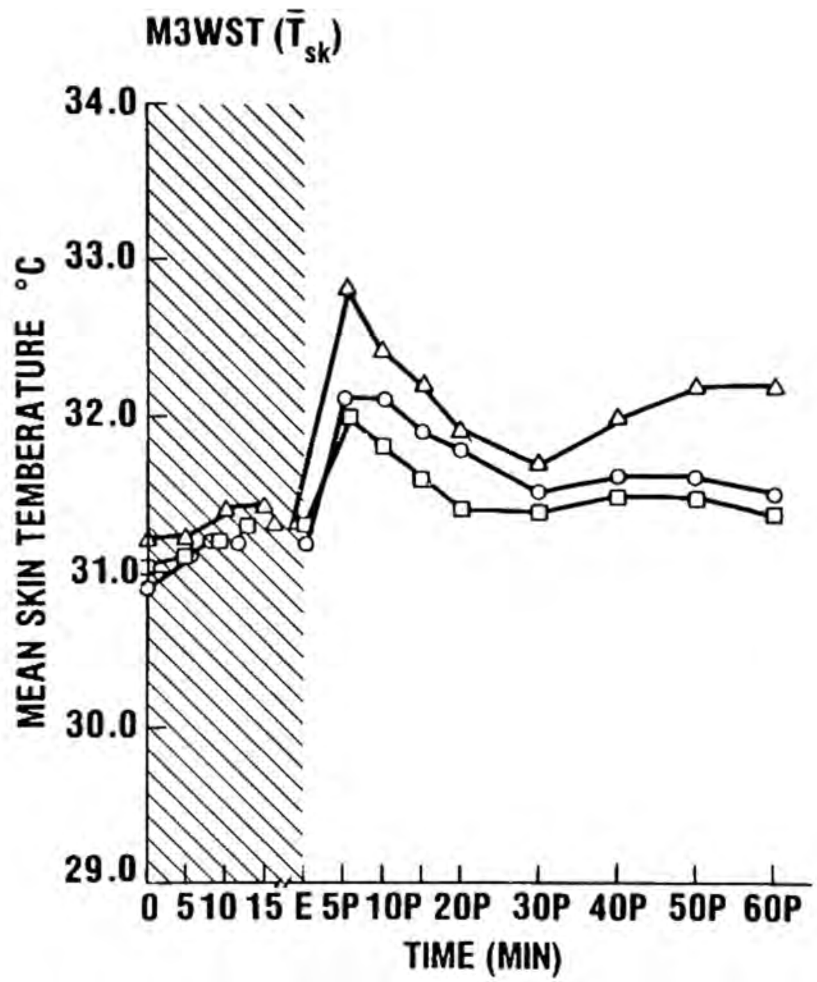
□ = joggers

o = sedentary group

Shaded area = the exercise time period

P = minutes post exercise

Nonconnected symbols and the letter E represent the end of exercise time period.



M3WST ($\bar{T}_{sk}$)
MEAN SKIN TEMBERATURE °C
34.0
33.0
32.0
31.0
30.0
29.0
0
5
10
15
E
5P
10P
20P
30P
40P
50P
60P
TIME (MIN)

FIGURE 12

TABLE 25. Mean weighted skin temperature (4 points), °C of subject groups at rest, during exercise, and during recovery.

Where: M = minutes during exercise

End = the end of exercise

P = minutes post exercise

( ) = n; number of subjects evaluated

Values are means ± S.D.

TABLE 25

Mean Weighted Skin Temperature (4 points), (M_4WST), °C

Time	Marathoners	Joggers	Sedentary
Rest	30.9±1.0 (15)	30.7±0.9 (17)	30.8±0.6 (15)
5M	30.5±0.9 (14)	30.6±0.8 (17)	30.5±0.6 (15)
10M	30.6±1.0 (14)	30.6±0.8 (16)	30.5±0.7 (14)
End	30.6±1.2 (14)	30.9±0.8 (15)	30.5±0.7 (15)
5P	32.6±1.4 (13)	31.7±0.8 (14)	31.8±0.9 (15)
10P	32.3±1.3 (15)	31.8±0.5 (13)	31.9±0.8 (15)
15P	32.1±1.3 (15)	31.5±0.6 (14)	31.9±0.7 (15)
20P	31.8±1.3 (15)	31.4±0.7 (14)	31.9±0.7 (15)
30P	31.6±1.1 (13)	31.5±0.7 (14)	31.6±0.6 (14)
40P	31.9±1.4 (14)	31.7±0.7 (13)	31.8±0.3 (13)
50P	32.1±1.2 (15)	31.7±0.7 (14)	31.8±0.5 (14)
60P	32.1±1.3 (15)	31.7±0.9 (13)	31.8±0.6 (14)

TABLE 26. The change in mean weighted skin temperature (4 points), °C between time intervals in each group.

Where: R = rest

M = minutes during exercise

End = the end of exercise

P = minutes post exercise

( ) = n; number of subjects evaluated

Asterisk(s) denotes significance of change within each group.

Values are means ± S.D.

TABLE 26

Change in Mean 4 Weighted Skin Temperature (M_4WST), °C

Time	Marathoners	Joggers	Sedentary
R-5M	-0.2±0.4 (14)	-0.1±0.3 (17)	-0.2±0.4 (15)
R-10M	-0.1±0.5 (14)	-0.0±0.4 (16)	-0.3±0.6 (14)
R-End	-0.2±0.7 (14)	0.2±0.6 (15)	-0.2±0.5 (15)
R-60P	1.2±0.8 (15)***	1.3±1.1 (12)**	1.0±0.7 (14)***
End-5P	1.9±0.6 (13)***	1.0±0.5 (13)***	1.3±0.9 (15)***

** $p < 0.01$; *** $p < 0.001$

FIGURE 13. Graph of mean weighted skin temperature (4 points), °C response of subject groups versus time.

Where: Δ = marathoners

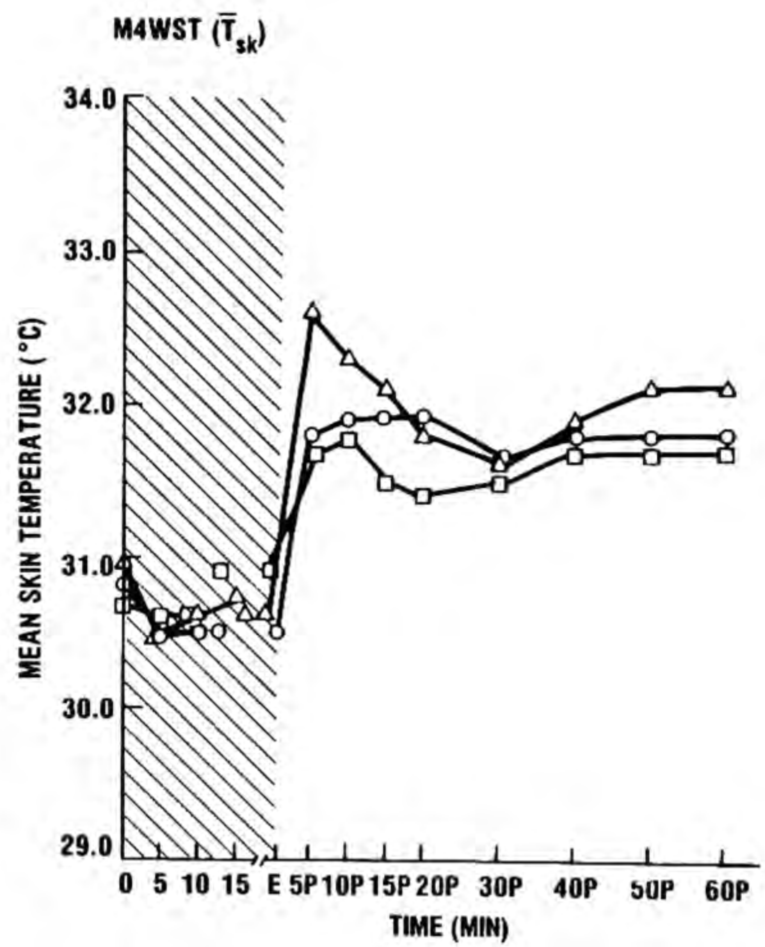
□ = joggers

o = sedentary group

Shaded area = the exercise time period

P = minutes post exercise

Nonconnected symbols and the letter E represent the end of exercise time period.



M4WST ($\overline{T}_{sk}$)
MEAN SKIN TEMPERATURE (°C)
34.0
33.0
32.0
31.0
30.0
29.0
0 5 10 15 E 5P 10P 15P 20P 30P 40P 50P 60P
TIME (MIN)

FIGURE 13

TABLE 27. Significant differences between M_3WST and M_4WST (M_3WST-M_4WST), °C in each subject group.

Where: M = minutes during exercise

End = the end of exercise

P = minutes post exercise

( ) = n; number of subjects evaluated

Asterisk(s) denotes significance of difference.

Values are means ± S.D.

TABLE 27

Significant Differences between M_3WST and M_4WST (M_3WST-M_4WST), °C

Time	Marathoners	Joggers	Sedentary
Rest	0.3±0.3 (15)**	0.3±0.4 (17)*	
5M	0.7±0.4 (14)***	0.5±0.4 (17)***	0.5±0.3 (15)***
10M	0.7±0.5 (14)***	0.6±0.4 (16)***	0.7±0.6 (14)***
End	0.7±0.5 (14)***	0.5±0.5 (15)**	0.6±0.6 (15)***

* $p = 0.02$; ** $p = 0.01$; *** $p = 0.001$

TABLE 28. Arithmetic mean 5 point skin temperature (M_5AST), °C of subject groups at rest, during exercise, and during recovery.

Where: M = minutes during exercise

End = the end of exercise

P = minutes post exercise

( ) = n; number of subjects evaluated.

Values are means ± S.D.

TABLE 28

Arithmetic Mean 5 Point Skin Temperature (M_5AST), °C

Time	Marathoners	Joggers	Sedentary
Rest	31.2±0.9 (14)	31.1±0.6 (17)	31.2±0.5 (15)
5M	30.7±1.1 (13)	31.0±0.7 (17)	31.1±0.5 (15)
10M	30.9±0.9 (13)	31.0±0.7 (16)	31.1±0.5 (14)
End	30.9±1.2 (13)	31.2±0.6 (15)	31.1±0.5 (15)
5P	32.7±1.3 (13)	32.1±0.7 (14)	32.3±0.8 (15)
10P	32.5±1.2 (15)	32.2±0.4 (13)	32.4±0.8 (15)
15P	32.3±1.1 (15)	31.9±0.6 (14)	32.4±0.7 (15)
20P	32.0±1.2 (15)	31.9±0.6 (14)	32.3±0.6 (15)
30P	31.7±1.0 (13)	31.8±0.6 (14)	31.9±0.5 (14)
40P	32.0±1.2 (14)	32.1±0.6 (13)	32.1±0.4 (13)
50P	32.3±1.0 (15)	32.1±0.5 (14)	32.2±0.5 (14)
60P	32.3±1.0 (15)	32.1±0.7 (13)	32.2±0.5 (14)

TABLE 29. The change in mean 5 point skin temperature (M_5AST), °C between time intervals in each group.

Where: R = rest

M = minutes during exercise

End = the end of exercise

P = minutes post exercise

( ) = n; number of subjects evaluated

Asterisk(s) denotes significance of change within each group.

Values are means ± S.D.

TABLE 29

Change in Arithmetic Mean 5 Point Skin Temperature (M_5AST), °C

Time	Marathoners	Joggers	Sedentary
R-5M	-0.2±0.4 (13)	-0.1±0.3 (17)	-0.2±0.4 (15)
R-10M	-0.1±0.4 (13)	-0.1±0.4 (16)	-0.2±0.5 (14)
R-End	-0.2±0.6 (13)	-0.1±0.5 (15)	-0.2±0.4 (15)
R-60P	1.2±0.6 (14)***	1.2±0.9 (12)***	1.0±0.6 (14)***
End-5P	1.7±0.5 (12)***	1.0±0.4 (13)***	1.2±0.7 (15)***

*** $p < 0.001$

FIGURE 14. Graph of arithmetic mean 5 point skin temperature (M_5AST), °C response of subject groups versus time.

Where: Δ = marathoners

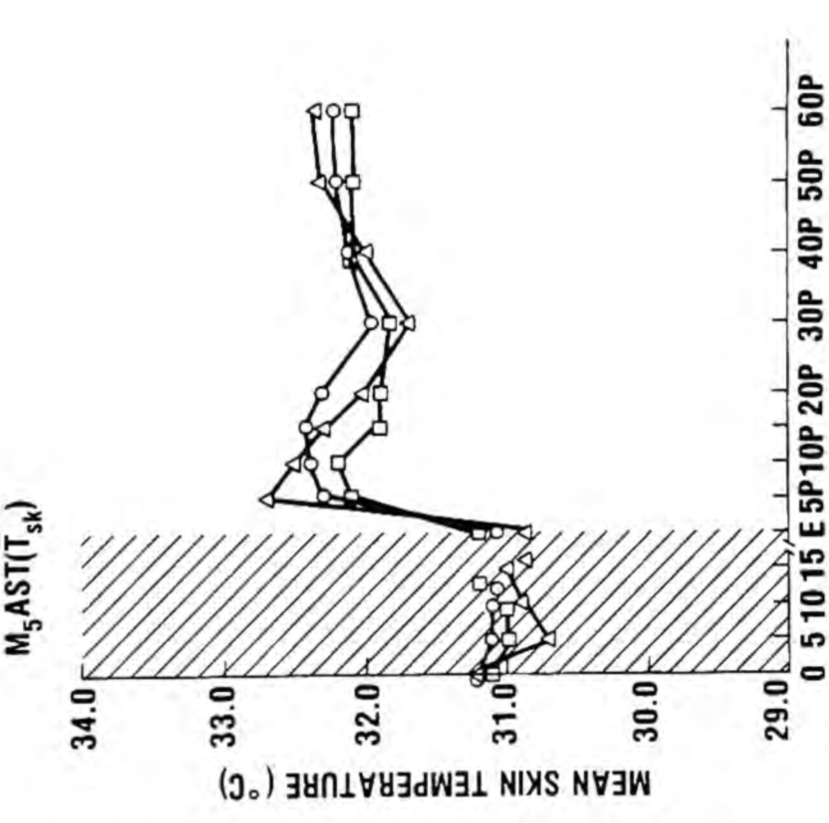
□ = joggers

o = sedentary group

Shaded area = the exercise time period

P = minutes post exercise

Nonconnected symbols and the letter E represent the end of exercise time period.



M_5AST($\bar{T}_{sk}$)
MEAN SKIN TEMPERATURE (°C)
34.0
33.0
32.0
31.0
30.0
29.0
0 5 10 15 E 5P 10P 20P 30P 40P 50P 60P
TIME (MIN)

FIGURE 14

TABLE 30. Significant differences between M_3WST and M_5AST (M_3WST-M_5AST), °C in each subject group.

Where: M = minutes during exercise

End = the end of exercise

P = minutes post exercise

( ) = n; number of subjects evaluated

Asterisk(s) denotes significance of difference.

Values are means ± S.D.

TABLE 30

Significant Differences between M_3WST and M_5AST (M_3WST-M_5AST), °C

Time	Marathoners	Joggers	Sedentary
Rest			-0.4±0.3 (15)***
5M	0.5±0.6 (13)**		
10M	0.4±0.5 (13)**		
End			
5P			
10P			
15P			-0.4±0.5 (15)**
20P		-0.4±0.6 (14)*	-0.5±0.4 (15)***
30P		-0.4±0.5 (14)**	-0.4±0.4 (14)**
40P		-0.6±0.5 (13)**	-0.5±0.4 (13)***
50P		-0.6±0.5 (14)***	-0.7±0.5 (14)***
60P		-0.8±0.7 (13)***	-0.7±0.4 (14)***

* $p < 0.02$; ** $p < 0.01$; *** $p < 0.001$

TABLE 31. Significant difference between M_4WST and M_5AST (M_4WST-M_5AST), °C in each subject group.

Where: M = minutes during exercise

End = the end of exercise

P = minutes post exercise

( ) = n; number of subjects evaluated

Asterisk(s) denotes significance of difference.

Values are means ± S.D.

TABLE 31

Significant Differences between M_4WST and M_5AST (M_4WST-M_5AST), °C

Time	Marathoners	Joggers	Sedentary
Rest	-0.3±0.3 (14)**	-0.4±0.4 (17)***	-0.5±0.3 (15)***
5M		-0.4±0.4 (17)***	-0.5±0.3 (15)***
10M	-0.3±0.3 (13)***	-0.4±0.4 (16)***	-0.6±0.3 (14)***
End	-0.3±0.4 (13)**	-0.4±0.5 (15)**	-0.5±0.3 (15)***
5P		-0.4±0.4 (14)**	-0.5±0.3 (15)***
10P		-0.4±0.4 (13)**	-0.4±0.2 (15)***
15P		-0.4±0.3 (14)***	-0.4±0.3 (15)***
20P		-0.4±0.3 (14)***	-0.4±0.2 (15)***
30P		-0.3±0.3 (14)***	-0.3±0.2 (14)***
40P		-0.4±0.3 (13)***	-0.3±0.2 (13)***
50P		-0.4±0.3 (14)***	-0.4±0.2 (14)***
60P		-0.4±0.3 (13)***	-0.4±0.2 (14)***

* $p < 0.02$; ** $p < 0.01$; *** $p < 0.001$

TABLE 32. Arithmetic mean 7 point skin temperature (M_7AST), °C of subject groups at rest, during exercise, and during recovery.

Where: M = minutes during exercise

End = the end of exercise

P = minutes post exercise

( ) = n; number of subjects evaluated.

Values are means ± S.D.

TABLE 32

Arithmetic Mean 7 Point Skin Temperature (M_7AST), °C

Time	Marathoners	Joggers	Sedentary
Rest	30.7±0.8 (13)	30.6±0.6 (17)	30.8±0.6 (14)
5M	30.3±0.8 (12)	30.4±0.6 (17)	30.5±0.6 (14)
10M	30.3±0.9 (12)	30.3±0.6 (16)	30.4±0.6 (11)
End	29.9±1.1 (12)	30.4±0.5 (15)	30.3±0.6 (12)
5P	31.6±1.4 (12)	31.0±0.6 (14)	31.2±0.8 (14)
10P	31.8±1.3 (14)	31.4±0.6 (13)	31.6±0.9 (14)
15P	31.7±1.3 (14)	31.3±0.8 (14)	31.8±0.9 (14)
20P	31.5±1.3 (14)	31.4±0.7 (14)	31.8±0.7 (14)
30P	31.3±1.0 (12)	31.4±0.6 (14)	31.6±0.6 (13)
40P	31.7±1.3 (13)	31.7±0.5 (13)	31.8±0.5 (13)
50P	31.9±1.1 (14)	31.7±0.5 (14)	32.0±0.5 (13)
60P	32.0±1.2 (14)	31.8±0.6 (13)	31.8±0.6 (13)

TABLE 33. The change in arithmetic mean 7 point skin temperature (M_7AST), °C between time intervals in each group.

Where: R = rest

M = minutes during exercise

End = the end of exercise

P = minutes post exercise

( ) = n; number of subjects evaluated

Asterisk(s) denotes significance of change within each group.

Values are means ± S.D.

TABLE 33

Change in Arithmetic Mean 7 Point Skin Temperature (M_7AST), °C

Time	Marathoners	Joggers	Sedentary
R-5	-0.2±0.3 (12)*	-0.2±0.3 (17)**	-0.3±0.3 (14)**
R-10	-0.3±0.4 (12)*	-0.3±0.3 (16)**	-0.4±0.4 (11)**
R-End	-0.7±0.5 (12)***	-0.3±0.4 (15)**	-0.5±0.5 (12)**
R-60P	1.5±0.7 (13)***	1.3±0.7 (12)***	1.3±0.4 (13)***
End-5P	1.5±0.6 (11)***	0.8±0.4 (13)***	1.1±0.6 (12)***

* $p < 0.02$; ** $p < 0.01$; *** $p < 0.001$

FIGURE 15. Graph of arithmetic mean 7 point skin temperature (M_7AST), °C response of subject groups versus time.

Where: Δ = marathoners

□ = joggers

o = sedentary group

Shaded area = the exercise time period

P = minutes post exercise

Nonconnected symbols and the letter E represent the end of exercise time period.

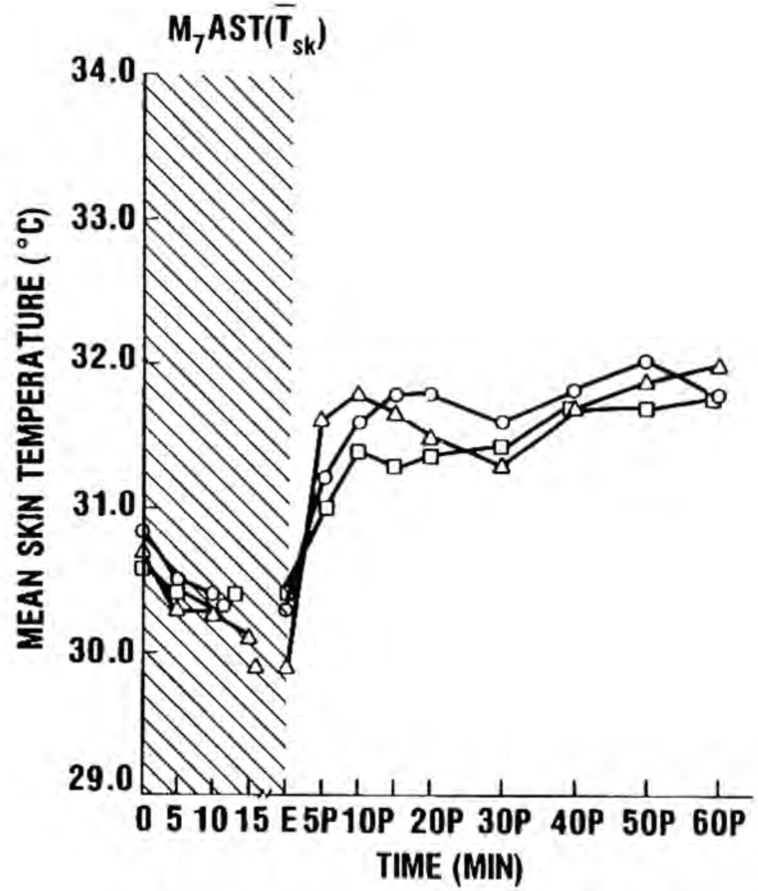

M7AST(T̄sk)
MEAN SKIN TEMPERATURE (°C)
34.0
33.0
32.0
31.0
30.0
29.0
0 5 10 15 E 5P 10P 20P 30P 40P 50P 60P
TIME (MIN)

FIGURE 15

TABLE 34. Significant differences between M_3WST and M_7AST (M_3WST-M_7AST), °C in each subject group.

Where: M = minutes during exercise

End = the end of exercise

P = minutes post exercise

( ) = n; number of subjects evaluated

Asterisk(s) denotes significance of difference.

Values are means ± S.D.

TABLE 34

Significant Differences between M_3WST and M_7AST (M_3WST-M_7AST), °C

Time	Marathoners	Joggers	Sedentary
Rest	0.7±0.3 (13)***		
5M	10.±0.3 (12)***	0.7±0.7 (17)***	0.6±0.4 (14)***
10M	1.1±0.4 (12)***	0.9±0.8 (16)***	0.9±0.5 (14)***
End	1.4±0.5 (12)***	0.9±0.8 (15)***	1.0±0.6 (12)***
5P	1.4±0.6 (12)***	1.0±0.9 (14)***	0.8±0.6 (14)***
10P	0.7±0.6 (14)***		0.5±0.6 (14)**
15P	0.6±0.6 (14)**		
20P	0.4±0.6 (14)*		
30P	0.4±0.6 (12)*		
40P			
50P			
60P			

* $p < 0.02$; ** $p < 0.01$; *** $p < 0.001$

TABLE 35. Significant differences between M_4WST and M_7AST (M_4WST-M_7AST), °C in each subject group.

Where: M = minutes during exercise

End = the end of exercise

P = minutes post exercise

( ) = n; number of subjects evaluated

Asterisk(s) denotes significance of difference.

Values are means ± S.D.

TABLE 35

Significant Differences between M_4WST and M_7AST (M_4WST-M_7AST), °C

Time	Marathoners	Joggers	Sedentary
Rest	0.3±0.3 (13)**		
5M	0.3±0.2 (12)***		
10M	0.4±0.3 (12)***		
End	0.7±0.4 (12)***	0.4±0.7 (15)*	0.3±0.3 (12)**
5P	1.1±0.4 (12)***	0.7±0.6 (14)***	0.6±0.4 (14)***
10P	0.6±0.4 (14)***		0.4±0.3 (14)**
15P	0.5±0.3 (14)***		
20P	0.4±0.4 (14)**		
30P	0.3±0.4 (12)*		
40P	0.3±0.4 (13)*		
50P	0.3±0.4 (14)*		
60P			

* $p < 0.02$; ** $p < 0.01$; *** $p < 0.001$

TABLE 36. Mean 5 (arithmetic) body temperature (M_5AT_b), °C of subject groups at rest, during exercise, and during recovery.

Where: M = minutes during exercise

End = the end of exercise

P = minutes post exercise

( ) = n; number of subjects evaulated

Asterisk(s) denotes significance of difference between groups.

Values are means ± S.D.

TABLE 36

Mean 5 (Arithmetic) Body Temperature (M_5AT_b), °C

Time	Marathoners	Joggers	Sedentary	Differences between groups, p-value[1]
Rest	35.0±0.2 (13)	35.0±0.3 (17)	35.2±0.2 (15)	
5M	34.9±0.3 (12)	35.0±0.3 (17)	35.2±0.2 (13)	S>M *
10M	35.0±0.3 (12)	35.0±0.3 (16)	35.2±0.2 (14)	
End	35.3±0.5 (12)	35.2±0.3 (15)	35.3±0.2 (15)	
5P	36.1±0.6 (12)	35.7±0.4 (14)	35.9±0.3 (15)	
10P	36.1±0.5 (14)	35.8±0.3 (13)	35.9±0.3 (15)	
15P	36.0±0.5 (14)	35.7±0.3 (14)	35.8±0.3 (15)	
20P	35.8±0.5 (14)	35.6±0.3 (14)	35.7±0.2 (15)	
30P	35.6±0.4 (12)	35.4±0.2 (14)	35.5±0.2 (14)	
40P	35.6±0.4 (13)	35.5±0.2 (13)	35.5±0.2 (13)	
50P	35.6±0.4 (14)	35.4±0.2 (14)	35.5±0.2 (14)	
60P	35.6±0.4 (14)	35.4±0.2 (13)	35.4±0.2 (14)	

(1) * $p < 0.02$

TABLE 37. The change in mean 5 (arithmetic) body temperature (M_5AT_b), °C between time intervals in each group.

Where: R = rest

M = minutes during exercise

End = the end of exercise

P = minutes post exercise

( ) = n; number of subjects evaluated

Asterisk(s) denotes significance of change within each group.

Values are means ± S.D.

TABLE 37

Changes in Mean 5 (Arithmetic) Body Temperature (M_5AT_b), °C

Time	Marathoners	Joggers	Sedentary
R-5M	-0.1±0.3 (12)	0.0±0.1 (17)	0.0±0.1 (15)
R-10M	0.0±0.2 (12)	0.1±0.1 (16)	0.0±0.2 (14)
R-End	0.3±0.3 (12)*	0.2±0.2 (15)**	0.1±0.2 (15)**
R-60P	0.6±0.2 (13)***	0.4±0.3 (12)***	0.2±0.3 (14)**
End-5P	0.9±0.2 (11)***	0.5±0.2 (13)***	0.6±0.2 (15)***

* $p < 0.02$; ** $p < 0.01$; *** $p < 0.001$

FIGURE 16. Graph of mean 5 (arithmetic) body temperature (M_5AT_b), °C response of subject groups versus time.

Where: Δ = marathoners

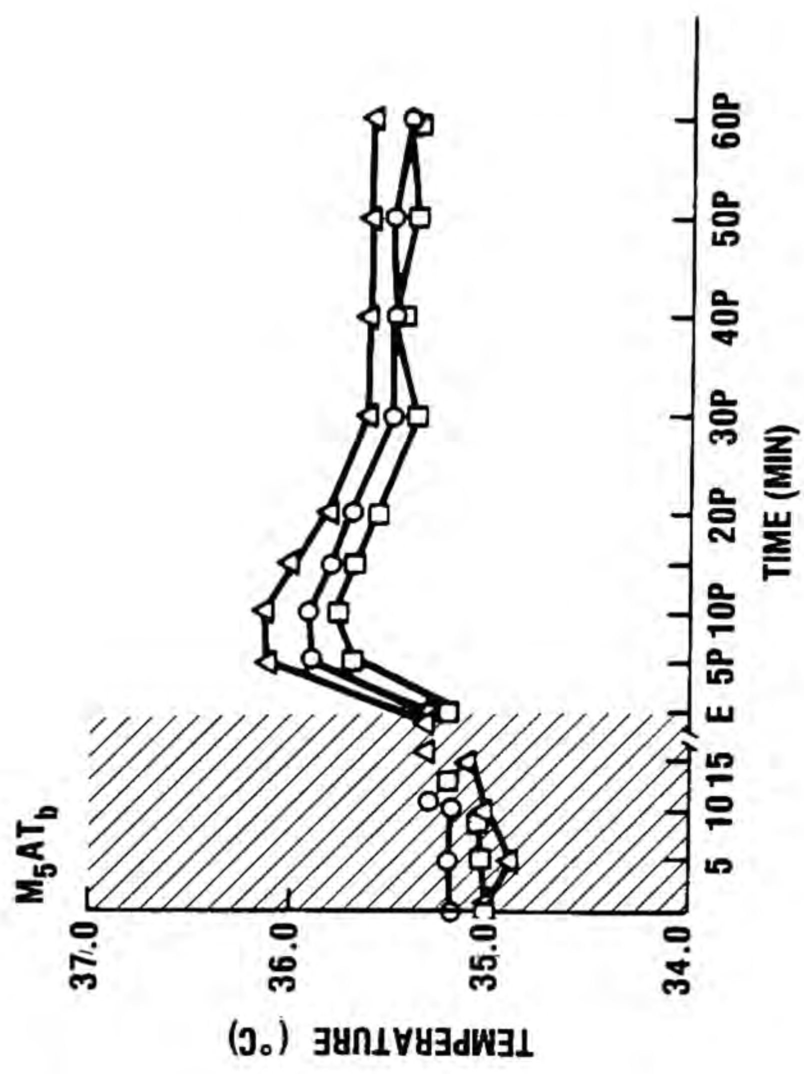
□ = joggers

o = sedentary group

Shaded area = the exercise time periods

P = minutes post exercise

Nonconnected symbols and the letter E represent the end of exercise time period.



M_5AT_b
TEMPERATURE (°C)
37.0
36.0
35.0
34.0
5
10
15
E
5P
10P
20P
30P
40P
50P
60P
TIME (MIN)

FIGURE 16

TABLE 38. Mean 4 (weighted) body temperature (M_4WT_b), °C of subject groups at rest, during exercise, and during recovery.

Where: M = minutes during exercise

End = the end of exercise

P = minutes post exercise

( ) = n; number of subjects evaluated

Asterisk(s) denotes significance of difference between groups.

Values are means ± S.D.

TABLE 38

Mean 4 (Weighted) Body Temperature (M_4WT_b), °C

Time	Marathoners	Joggers	Sedentary	Differences between groups, p-Value [1]
Rest	34.9±0.3 (14)	34.9±0.4 (17)	35.0±0.2 (15)	
5M	34.8±0.3 (13)	34.8±0.4 (17)	35.0±0.2 (15)	
10M	34.9±0.3 (13)	34.9±0.3 (16)	35.0±0.3 (14)	
End	35.1±0.5 (13)	35.1±0.3 (15)	35.1±0.2 (15)	
5P	36.1±0.6 (12)	35.6±0.4 (14)	35.7±0.3 (15)	M>J **
10P	36.0±0.5 (14)	35.7±0.3 (13)	35.7±0.3 (15)	
15P	35.9±0.5 (14)	35.5±0.3 (14)	35.7±0.3 (15)	M>J *
20P	35.7±0.5 (14)	35.4±0.3 (14)	35.5±0.2 (15)	
30P	35.6±0.4 (12)	35.3±0.2 (14)	35.4±0.2 (14)	
40P	35.6±0.5 (13)	35.3±0.2 (13)	35.4±0.2 (13)	
50P	35.6±0.4 (14)	35.3±0.3 (14)	35.3±0.2 (14)	
60P	35.5±0.4 (14)	35.2±0.3 (13)	35.3±0.2 (14)	

* $p < 0.02$, ** $p < 0.01$

TABLE 39. The change in mean 4 (weighted) body temperature (M_4WT_b), °C between time intervals in each group.

Where: R = rest

M = minutes during exercise

End = the end of exercise

P = minutes post exercise

( ) = n; number of subjects evaluated

Asterisk(s) denotes significance of change within each group.

Values are means ± S.D.

TABLE 39

Change in Mean 4 (Weighted) Body Temperature (M_4WT_b), °C

Time	Marathoners	Joggers	Sedentary
R-5M	-0.1±0.1 (13)	-0.1±0.1 (17)	0.0±0.1 (15)
R-10M	0.0±0.2 (13)	0.1±0.1 (16)	0.0±0.2 (14)
R-End	0.3±0.4 (13)*	0.2±0.2 (15)***	0.1±0.2 (15)
R-60P	0.6±0.3 (14)***	0.4±0.4 (12)**	0.3±0.3 (14)**
End-5P	0.9±0.3 (12)***	0.5±0.2 (13)***	0.6±0.3 (15)***

* $p < 0.02$; ** $p < 0.01$; *** $p < 0.001$

FIGURE 17. Graph of mean 4 (weighted) body temperature (M_4WT_b), °C response of subject groups versus time.

Where: Δ = marathoners

□ = joggers

o = sedentary group

Shaded area = the exercise time period

P = minutes post exercise

Nonconnected symbols and the letter E represent the end of exercise time period.

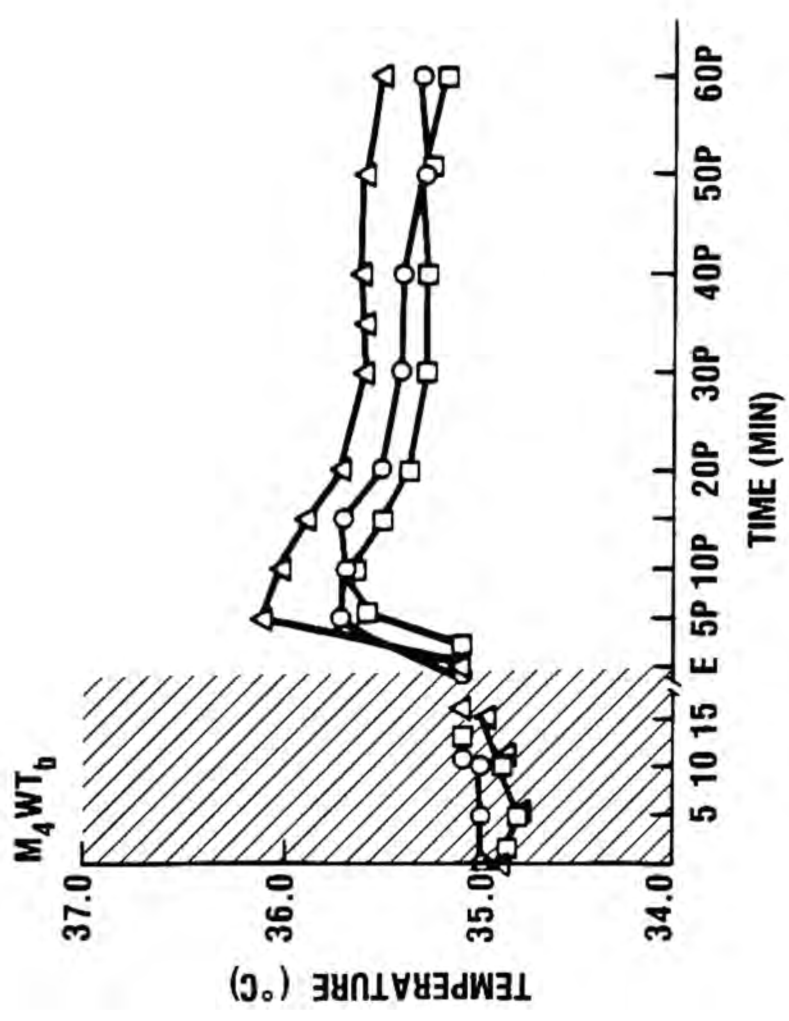

M4WTb
37.0
36.0
35.0
34.0
TEMPERATURE (°C)
5 10 15 E 5P 10P 20P 30P 40P 50P 60P
TIME (MIN)

FIGURE 17

TABLE 40. Mean 3 (weighted) body temperature (M_3WT_b), °C of subject groups at rest, during exercise, and during recovery.

Where: M = minutes during exercise

End = the end of exercise

P = minutes post exercise

( ) = n; number of subjects evaluated

Asterisk(s) denotes significance of difference between groups.

Values are means ± S.D.

TABLE 40

Mean 3 (Weighted) Body Temperature (M_3WT_b), °C

Time	Marathoners	Joggers	Sedentary	Differences between groups, p-Value (1)
Rest	35.0±0.2 (14)	35.0±0.4 (17)	35.1±0.2 (15)	
5M	35.0±0.3 (13)	35.0±0.4 (17)	35.2±0.2 (15)	
10M	35.1±0.3 (13)	35.1±0.4 (16)	35.3±0.2 (14)	
End	35.4±0.4 (13)	35.3±0.3 (15)	35.3±0.2 (15)	
5P	36.2±0.5 (12)	35.7±0.4 (14)	35.8±0.4 (15)	M>J ***
10P	36.0±0.5 (14)	35.7±0.3 (13)	35.8±0.3 (15)	M>J *
15P	35.9±0.4 (14)	35.6±0.3 (14)	35.7±0.3 (15)	M>J **
20P	35.7±0.5 (14)	35.4±0.3 (14)	35.5±0.3 (15)	
30P	35.6±0.4 (12)	35.3±0.3 (14)	35.3±0.2 (14)	
40P	35.6±0.5 (13)	35.2±0.3 (14)	35.3±0.2 (13)	
50P	35.6±0.5 (14)	35.2±0.3 (14)	35.3±0.3 (14)	M>J *
60P	35.5±0.5 (14)	35.1±0.4 (15)	35.2±0.3 (14)	

(1) * $p < 0.02$; ** $p < 0.01$; *** $p < 0.001$

TABLE 41. The change in mean 3 (weighted) body temperature (M_3WT_b), °C between time intervals in each group.

Where: R = rest

M = minutes during exercise

End = the end of exercise

P = minutes post exercise

( ) = n; number of subjects evaluated

Asterisk(s) denotes significance of change within each group.

Values are means ± S.D.

TABLE 41

Changes in Mean 3 (Weighted) Body Temperature (M_3WT_b)

Time	Marathoners	Joggers	Sedentary
R-5M	0.0±0.1 (13)	0.0±0.1 (17)	0.1±0.1 (15)
R-10M	0.1±0.2 (13)	0.2±0.2 (16)***	0.2±0.2 (14)***
R-End	0.4±0.3 (13)***	0.3±0.3 (15)***	0.3±0.1 (15)***
R-60P	0.5±0.4 (14)***	0.3±0.6 (12)	0.1±0.3 (14)
End-5P	0.8±0.3 (12)***	0.4±0.2 (13)***	0.5±0.3 (15)***

*** $p < 0.001$

FIGURE 18. Graph of mean 3 (weighted) body temperature (M_3WT_b), °C response of subject groups versus time.

Where: Δ = marathoners

□ = joggers

o = sedentary group

Shaded area = the exercise time period

P = minutes post exercise

Nonconnected symbols and the letter E represent the end of exercise time period.

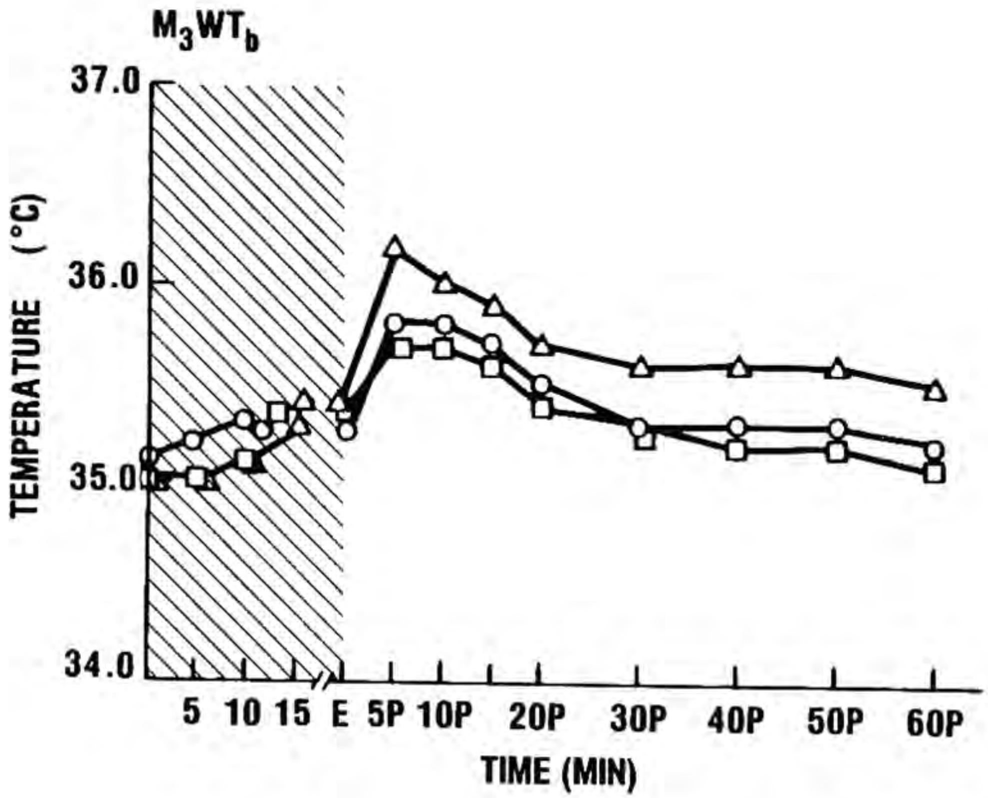

M3WTb
37.0
36.0
35.0
34.0
TEMPERATURE (°C)
5 10 15 E 5P 10P 20P 30P 40P 50P 60P
TIME (MIN)

FIGURE 18

TABLE 42. Mean 5 (arithmetic) change in body heat content ($M_5A\Delta S$), kcal of subjects during exercise and recovery.

Where: M = minutes during exercise

End = the end of exercise

P = minutes post exercise

All values of $M_5A\Delta S$ are mean values of the individual groups at each time point, not a mean value of individual subjects.

TABLE 42

Mean 5 (Arithmetic) Change in Body Heat Content ($M_5A\Delta S$), kcal

Time	Marathoners	Joggers	Sedentary
5M	-5.66	0	0
10M	0	0	0
End	16.98	12.65	6.49
5P	45.28	31.62	38.94
10P	0	6.32	0
15P	-5.66	-6.32	-6.49
20P	-11.32	-6.32	-6.49
30P	-11.32	-12.65	-12.98
40P	0	6.32	0
50P	0	-6.32	0
60P	0	0	-6.49

TABLE 43. Mean 5 (arithmetic) heat storage (M_5AS), kcal of subject groups during exercise and during recovery.

Where: M = minutes during exercise

End = the end of exercise

P = minutes post exercise

( ) = n; number of subjects evaluated

Asterisk(s) denotes significance of difference between groups.

Values are means ± S.D.

TABLE 43

Mean 5 (Arithmetic) Heat Storage (M_5AS), Kcal

Time	Marathoners	Joggers	Sedentary	Differences between groups, p-Value (1)
5M	-7.3±14.5 (12)	-2.7±6.1 (17)	-2.3±9.3 (15)	
10M	-0.9±8.5 (12)	3.1±7.9 (16)	2.9±13.7 (14)	
End	13.9±17.9 (12)	13.7±14.8 (15)	8.4±11.0 (15)	
5P	62.1±22.0 (11)	48.5±17.1 (14)	45.9±20.9 (15)	
10P	59.1±20.6 (13)	51.5±16.1 (12)	45.6±20.1 (15)	
15P	52.9±18.0 (13)	44.0±15.1 (13)	39.4±16.8 (15)	
20P	42.2±17.4 (13)	38.7±16.4 (13)	30.6±16.6 (15)	
30P	31.7±15.7 (11)	31.2±18.4 (13)	17.6±18.9 (14)	
40P	32.0±17.2 (12)	29.9±19.3 (12)	20.9±15.2 (13)	
50P	34.9±17.1 (13)	28.9±18.2 (13)	18.5±18.8 (14)	
60P	33.0±15.0 (13)	26.4±21.2 (12)	15.0±17.6 (14)	M>S **

(1) ** $p < 0.01$

FIGURE 19. Graph of mean 5 (arithmetic) heat storage (M_5AS), kcal response of subject groups versus time.

Where: Δ = marathoners

□ = joggers

o = sedentary group

Shaded area = the exercise time period

P = minutes post exercise

Nonconnected symbols and the letter E represent the end of exercise time period.

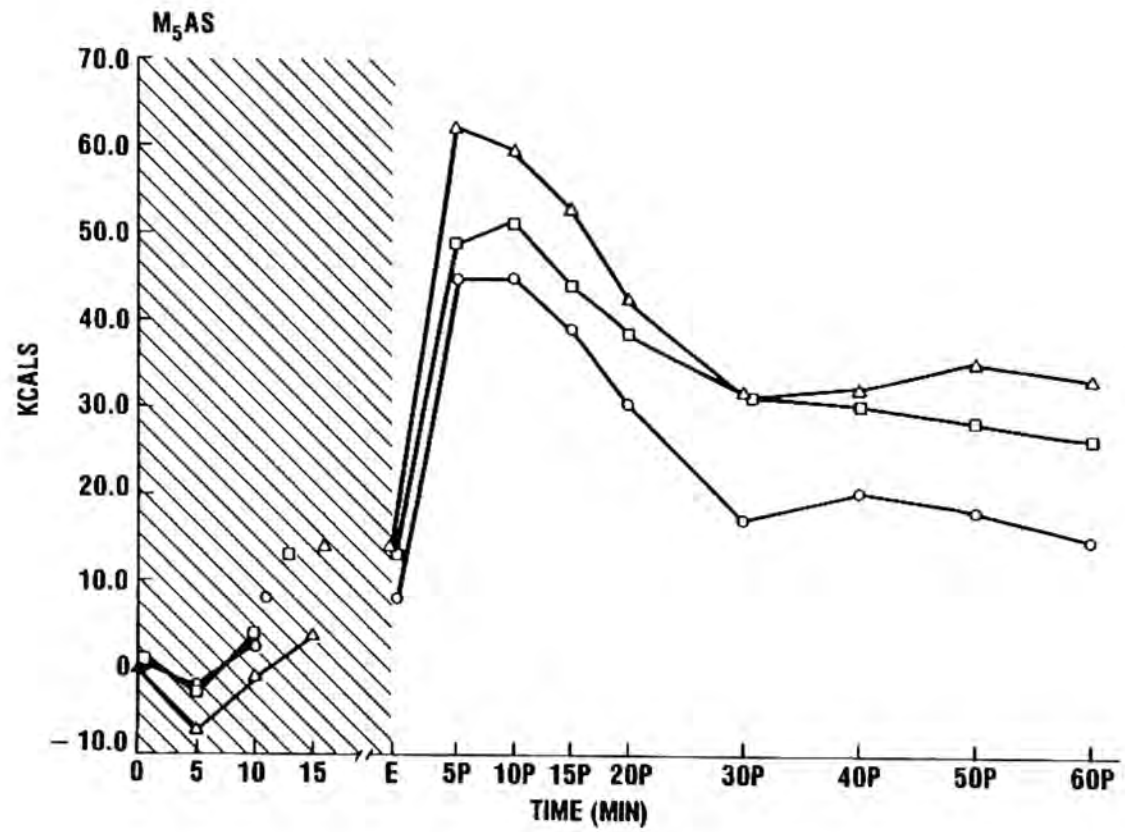

M$_5$AS
KCALS
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0
– 10.0
0
5
10
15
E
5P
10P
15P
20P
30P
40P
50P
60P
TIME (MIN)

FIGURE 19

TABLE 44. Mean 4 (weighted) change in body heat content ($M_4W\Delta S$), kcal of subjects during exercise and recovery.

Where: M = minutes during exercise

End = the end of exercise

P = minutes post exercise

All values of $M_4W\Delta S$ are mean values of the indiviudal groups at each time point, not a mean value of individual subjects.

TABLE 44

Mean 4 (Weighted) Change in Body Heat Content ($M_4W\Delta S$), kcal

Time	Marathoners	Joggers	Sedentary
5M	-5.66	-6.32	0
10M	5.66	6.32	0
End	11.32	12.65	6.49
5P	56.60	31.62	38.94
10P	-5.66	-6.32	0
15P	-5.66	-12.65	0
20P	-11.32	-6.32	-12.98
30P	-5.66	-6.32	-6.99
40P	0	0	0
50P	0	0	-6.49
60P	-5.66	-6.32	0

TABLE 45. Mean 4 (weighted) heat storage (M_4WS), kcal of subject groups during exercise and during recovery.

Where: M = minutes during exercise

End = the end of exercise

P = minutes post exercise

( ) = n; number of subjects evaluated

Asterisk(s) denotes significance of difference between groups.

Values are means ± S.D.

TABLE 45

Mean 4 (Weighted) Heat Storage (M_4WS), Kcal

Time	Marathoners	Joggers	Sedentary
5M	-4.4±8.4 (13)	-2.0±6.1 (17)	-4.0±10.3 (15)
10M	-1.4±9.7 (13)	4.1±8.4 (16)	0.2±15.6 (14)
End	13.8±18.0 (13)	15.6±13.9 (15)	6.9±11.6 (15)
5P	65.7±20.3 (12)	49.3±15.2 (14)	45.4±24.4 (15)
10P	60.6±19.8 (14)	53.0±14.5 (12)	46.0±21.8 (15)
15P	54.8±17.6 (14)	47.1±14.2 (13)	39.8±17.9 (15)
20P	45.3±18.3 (14)	41.0±15.2 (13)	31.9±19 (15)
30P	35.7±16.6 (12)	35.4±19.7 (13)	21.3±19.9 (14)
40P	34.7±18.8 (13)	33.0±20.9 (12)	24.4±17.9 (13)
50P	36.9±18.8 (14)	30.8±18.1 (13)	19.9±21.4 (14)
60P	33.3±19.3 (14)	27.3±24.9 (12)	16.0±18.9 (14)

FIGURE 20. Graph of mean 4 (weighted) heat storage (M_4WS), kcal response of subject groups versus time.

Where: Δ = marathoners

□ = joggers

o = sedentary group

Shaded area = the exercise time period

P = minutes post exercise

Nonconnected symbols and the letter E represent the end of exercise time period.

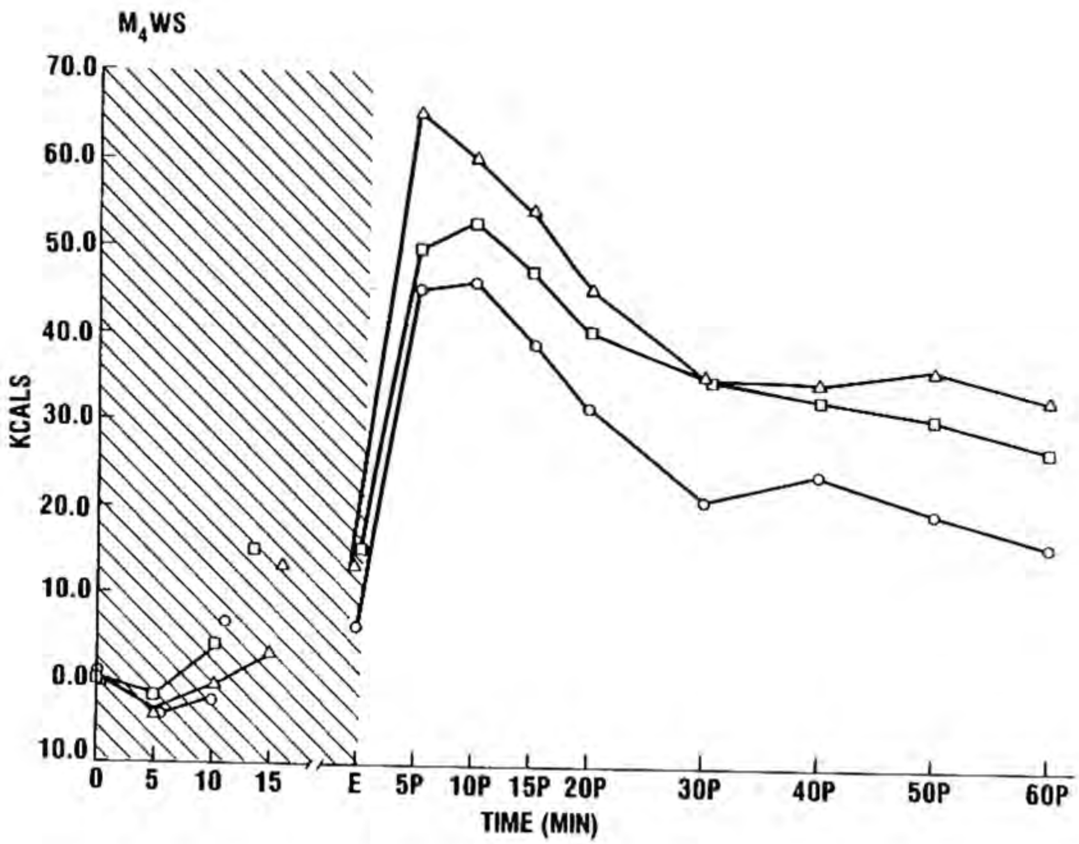

M4WS
KCALS
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.00
10.0
0
5
10
15
E
5P
10P
15P
20P
30P
40P
50P
60P
TIME (MIN)

FIGURE 20

TABLE 46. Mean 3 (weighted) change in body heat content ($M_3W\Delta S$), kcal of subjects during exercise and recovery.

Where: M = minutes during exercise

End = the end of exercise

P = minutes post exercise

All values of $M_3W\Delta S$ are mean values of the individual groups at each time point, not a mean value of individual subjects.

TABLE 46

Mean 3 (Weighted) Change in Body Heat Content ($M_3W\Delta S$), kcal

Time	Marathoners	Joggers	Sedentary
5M	0	0	6.49
10M	5.66	6.32	6.49
End	16.98	12.65	0
5P	45.28	25.30	32.45
10P	-11.32	0	0
15P	-5.66	-6.32	-6.49
20P	-11.32	-12.65	-12.98
30P	-5.66	-6.32	-12.98
40P	0	-6.32	0
50P	0	0	0
60P	-5.66	-6.32	-6.49

TABLE 47. Mean 3 (weighted) heat storage (M_3WS), kcal of subject groups during exercise and recovery.

Where: M = minutes during exercise

End = the end of exercise

P = minutes post exercise

( ) = n; number of subjects evaluated

Asterisk(s) denotes significance of difference between groups.

Values are means ± S.D.

TABLE 47

Mean 3 (Weighted) Heat Storage (M_3WS), Kcal

Time	Marathoners	Joggers	Sedentary	Differences between groups, p-Value (1)
5M	0.2±7.8 (15)	2.8±9.0 (17)	5.3±10.7 (15)	
10M	5.2±10.3 (13)	11.6±11.3 (16)	12.5±12.7 (14)	
End	20.6±16.2 (13)	19.9±17.5 (15)	17.7±10.1 (15)	
5P	63.8±19.0 (12)	49.4±20.3 (14)	49.2±25.1 (15)	
10P	56.2±18.6 (14)	49.2±19.8 (12)	46.9±22.7 (15)	
15P	50.8±17.2 (14)	43.4±19.4 (13)	37.5±17.0 (15)	
20P	39.1±18.1 (14)	35.8±20.9 (13)	27.6±18.7 (15)	
30P	30.5±16.7 (12)	28.8±25.8 (13)	16.5±16.6 (14)	
40P	29.8±20.2 (13)	24.6±27.0 (13)	17.9±16.6 (13)	
50P	32.0±21.2 (14)	23.0±27.6 (13)	12.4±20.4 (14)	M>S *
60P	27.0±22.3 (14)	16.5±34.5 (12)	7.7±18.5 (14)	M>S *

(1) * $p < 0.02$

FIGURE 21. Graph of mean 3 (weighted) heat storage (M_3WS), kcal response of subject groups versus time.

Where: Δ = marathoners

$\square$ = joggers

o = sedentary group

Shaded area = the exercise time period

P = minutes post exercise

Nonconnected symbols and the letter E represent the end of exercise time period.

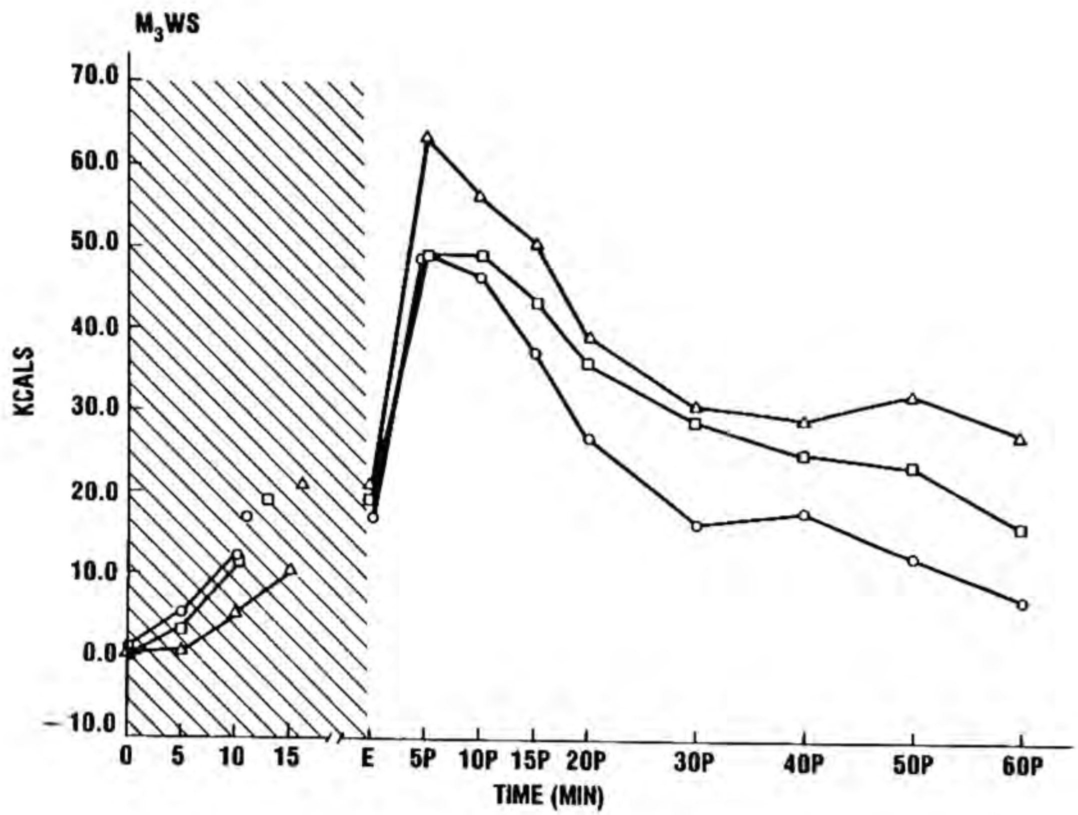

M3WS
KCALS
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
- 10.0
0
5
10
15
E
5P
10P
15P
20P
30P
40P
50P
60P
TIME (MIN)

FIGURE 21

TABLE 48. Mean 4 (arithmetic) heat gradient (M_5AH_{grad}), °C of subject groups at rest, during exercise, and during recovery.

Where: M = minutes during exercise

End = the end of exercise

P = minutes post exercise

( ) = n; number of subjects evaluated

Values are means ± S.D.

TABLE 48

Mean 5 (Arithmetic) Heat Gradient (M_5AH_{grad}), °C

Time	Marathoners	Joggers	Sedentary
Rest	5.6±0.9 (13)	5.8±0.6 (17)	5.9±0.5 (15)
5M	6.1±1.2 (12)	6.0±0.7 (17)	6.1±0.6 (15)
10M	6.0±0.9 (12)	6.1±0.7 (16)	6.2±0.5 (14)
End	6.4±1.1 (11)	6.0±0.7 (15)	6.4±0.6 (15)
5P	5.0±1.1 (12)	5.4±0.7 (14)	5.4±0.8 (15)
10P	5.3±1.1 (14)	5.4±0.4 (13)	5.3±0.7 (15)
15P	5.4±1.1 (14)	5.6±0.7 (14)	5.1±0.7 (15)
20P	5.7±1.2 (14)	5.6±0.7 (14)	5.1±0.7 (15)
30P	5.8±0.9 (12)	5.5±0.7 (14)	5.4±0.6 (14)
40P	5.2±1.2 (13)	5.1±0.7 (13)	5.0±0.4 (13)
50P	4.9±1.1 (14)	5.0±0.6 (14)	4.9±0.5 (14)
60P	4.8±1.1 (14)	4.9±0.8 (13)	4.8±0.6 (14)

TABLE 49. The change in mean 5 (arithmetic) heat gradient (M_5AH_{grad}), °C between time intervals in each group.

Where: R = rest

M = minutes during exercise

End = the end of exercise

P = minutes post exercise

( ) = n; number of subjects evaluated

Asterisk(s) denote significance of change within each group and between groups.

Values are means ± S.D.

TABLE 49

Change in Mean 5 (Arithmetic) Heat Gradient (M_5AH_{grad}), °C

Time	Marathoners	Joggers	Sedentary	Differences between groups, p-Value (1)
R-5M	0.4±0.7 (12)	0.2±0.3 (17)	0.2±0.4 (15)	
R-10M	0.2±0.5 (12)	0.2±0.4 (16)	0.3±0.5 (14)	
R-End	0.7±0.5 (12)	0.2±0.5 (15)	0.4±0.5 (15)	M>J *
R-60P	-0.9±0.6 (13)***	-1.2±0.9 (12)***	-1.1±0.6 (14)***	

(1) * $p < 0.02$; *** $p < 0.001$

TABLE 50. Mean 4 (weighted) heat gradient (M_4WH_{grad}), °C of subject groups at rest, during exercise, and during recovery.

Where: M = minutes during exercise

End = the end of exercise

P = minutes post exercise

( ) = n; number of subjects evaluated

Values are means ± S.D.

TABLE 50

Mean 4 (Weighted) Heat Gradient (M_4WH_{grad}), °C

Time	Marathoners	Joggers	Sedentary
Rest	5.9±1.1 (14)	6.3±0.8 (17)	6.4±0.6 (15)
5M	6.3±1.0 (13)	6.4±0.8 (17)	6.7±0.7 (15)
10M	6.3±1.0 (13)	6.5±0.8 (16)	6.8±0.7 (14)
End	6.7±1.1 (13)	6.4±0.9 (15)	6.9±0.8 (15)
5P	5.0±1.1 (12)	5.8±0.9 (14)	5.9±0.9 (15)
10P	5.4±1.2 (14)	5.8±0.6 (13)	5.7±0.8 (15)
15P	5.6±1.2 (14)	6.0±0.7 (14)	5.6±0.7 (15)
20P	5.8±1.3 (14)	6.0±0.8 (14)	5.5±0.8 (15)
30P	5.9±1.0 (12)	5.8±0.8 (14)	5.7±0.7 (14)
40P	5.3±1.4 (13)	5.5±0.8 (13)	5.3±0.4 (13)
50P	5.1±1.3 (14)	5.4±0.8 (14)	5.3±0.5 (14)
60P	5.0±1.3 (14)	5.3±1.0 (13)	5.3±0.6 (14)

TABLE 51. The change in mean 4 (weighted) heat gradient (M_4WH_{grad}), °C between time intervals in each group.

Where: M = minutes during exercise

End = the end of exercise

P = minutes post exercise

( ) = n; number of subjects evaluated

Asterisk(s) denote significance of change within each group and between groups.

Values are means ± S.D.

TABLE 51

Change in Mean 4 (Weighted) Heat Gradient (M_4WH_{grad}), °C

Time	Marathoners	Joggers	Sedentary	Differences between groups, p-Value (1)
R-5M	0.2±0.4 (13)	0.1±0.4 (17)	0.3±0.4 (15)*	
R-10M	0.2±0.5 (13)	0.1±0.5 (16)	0.5±0.5 (14)**	
R-End	0.7±0.6 (13)**	0.1±0.6 (15)	0.5±0.5 (15)**	M>J *
R-60P	-0.9±0.8 (14)***	-1.2±1.1 (12)**	1.1 ±0.7 (14)***	

(1) * $p < 0.02$; ** $p < 0.01$; *** $p < 0.001$

TABLE 52. Mean 3 (weighted) heat gradient (M_3WH_{grad}), °C of subject groups at rest, during exercise, and during recovery.

Where: M = minutes during exercise

End = the end of exercise

P = minutes post exercise

( ) = n; number of subjects evaluated

Asterisk(s) denotes significance of difference between groups.

Values are means ± S.D.

TABLE 52

Mean 3 (Weighted) Heat Gradient (M_3WH_{grad}), °C

Time	Marathoners	Joggers	Sedentary	Differences between groups, p-Value (1)
Rest	5.6±1.0 (14)	6.0±0.8 (17)	6.3±0.6 (15)	S>M *
5M	5.7±0.9 (13)	5.9±0.9 (17)	6.1±0.7 (15)	
10M	5.6±1.0 (13)	5.9±1.0 (16)	6.1±0.7 (14)	
End	6.0±1.0 (13)	5.9±1.0 (15)	6.3±0.8 (15)	
5P	4.8±1.0 (12)	5.5±1.0 (14)	5.6±1.1 (15)	
10P	5.3±1.0 (14)	5.8±0.7 (13)	5.6±0.9 (15)	
15P	5.5±1.1 (14)	5.9±0.7 (14)	5.6±0.8 (15)	
20P	5.8±1.3 (14)	6.0±0.8 (14)	5.6±0.8 (15)	
30P	5.8±1.0 (12)	5.9±0.9 (14)	5.8±0.6 (14)	
40P	5.3±1.3 (13)	5.7±0.9 (14)	5.5±0.5 (13)	
50P	5.0±1.3 (14)	5.6±1.0 (14)	5.5±0.6 (14)	
60P	5.0±1.4 (14)	5.6±1.3 (13)	5.5±0.6 (14)	

(1) * $p < 0.02$

TABLE 53. The change in mean 3 (weighted) heat gradient (M_3WH_{grad}), °C between time intervals in each group.

Where: M = minutes during exercise

End = the end of exercise

P = minutes post exercise

( ) = n; number of subjects evaluated

Asterisk(s) denotes significance of difference within each group.

Values are means ± S.D.

TABLE 53

Change in Mean 3 (Weighted) Heat Gradient (M_3WH_{grad}), °C

Time	Marathoners	Joggers	Sedentary
R-5M	0.0±0.5 (13)	-0.1±0.5 (17)	-0.2±0.5 (15)
R-10M	-0.1±0.7 (13)	-0.2±0.6 (16)	-0.1±0.5 (14)
R-End	0.3±0.7 (13)	0.1±0.8 (15)	0.0±0.5 (15)
R-60	-0.6±0.9 (14)	-0.7±1.3 (12)	-0.7±0.4 (14)**

** $p < 0.01$

TABLE A. Significant correlations between $\dot{V}O_2max$ and temperature at rest and during exercise. Values express "r" values. Negative values express inverse relationship. Asterisk(s) denotes significances of rejection of Null hypothesis that the variably are independent.

Where: M = minutes of exercise

End = the end of exercise

TABLE A

Significant Correlations between $\dot{V}O_2max$ and Temperature at Rest and during Exercise

	Rest	5M	10M	End
Forearm	-0.3*			-0.4**
Hand	-0.4**	-0.3*		
Abdomen	0.5***	0.5***	0.5***	
Rectal	-0.3*	-0.3*	-0.3*	
Lumbar			0.3*	
Calf	0.2*	0.3*	0.3*	0.3**

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

TABLE B. Significant correlations between $\dot{V}O_2max$ and temperature during recovery. Values express "r" values. Asterisk(s) denotes significance of rejection of Null hypothesis that the variables are independent.

Where: P = minutes post exercise

TABLE B

Significant Correlations between $\dot{V}O_2max$ and Temperature during Recovery

	5P	10P	15P	20P	30P	40P	50P	60P
Chest	0.3***	0.3*	0.3*					
Abdomen	0.4**	0.4*						
Rectal	0.4**	0.5***	0.5***	0.5***	0.4**	0.3*		0.3*
Thigh	0.5***	0.4**						
Calf	0.4**	0.4**	0.4**	0.3*	0.3*	0.3*	0.3*	

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

TABLE C. Significant correlations between body fat and temperature at rest, during exercise, and during recovery. Values express "r" values. Negative values express inverse relationship. Asterisk(s) denotes significance of rejection of Null hypothesis that the variables are independent.

Where: M = minutes of exercise

End = the end of exercise

P = minutes post exercise

TABLE C

Significant Correlations between Body Fat and Temperature at Rest, during Exercise, and during Recovery

	Rest	5M	10M	END	5P	10P	15P	20P +
Chest	-0.3*	-0.3*	-0.3*		-0.4***	-0.5***	-0.4**	-0.4**
Forearm	0.3*	0.2*	0.3*	0.4**				
Hand	0.4***	0.4***	0.5***	0.6***	0.2*			
Abdomen	-0.5***	-0.5***	-0.5***	-0.3*	-0.5***	-0.4**	-0.3*	
Rectal	0.3*	0.3*	0.3*			-0.3*	-0.3*	
Scapula				-0.3*				
Lumbar			-0.4**	-0.3**				
Calf						-0.3*	-0.3*	

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

+ Note 30P-60P; no significant correlations were found

TABLE D. Blood lactate concentration, mg/dl of subject groups at rest, the end of exercise, and at one hour post exercise.

Where: End = the end of exercise

P = minutes post exercise.

Values are means ± S.D.

TABLE D

Blood Lactate Concentration, mg/dl

Time	Marathoners	Joggers	Sedentary
Rest	8.4±2.16	8.8±3.2	7.9±1.4
End	83.1±20.4	93.6±29.2	77.0±24.2
60P	21.2±7.5	25.7±9.8	24.2±11.9

TABLE E. Skinfold thickness measurements, mm of seven skin sites used in determining percent body fat. Asterisk(s) denotes significance of difference between groups. Values are means ± S.D.

TABLE E

Skinfold Thickness, mm

Site	Marathoners	Joggers	Sedentary	Differences between groups, p-Value (1)
Chest	8.0±2.3	13.9±6.3	13.8±7.0	M<J ***, M<S **
Subscapalar	9.2±1.6	13.7±4.6	12.2±3.1	M<J&S ***
Triceps	6.4±2.1	9.4±3.2	9.9±3.6	M<J **, M<S **
Axilla	6.5±1.3	10.4±4.1	10.1±3.9	M<J&S ***
Abdomen	10.2±3.5	19.1±6.6	20.5±8.5	M>J&S ***
Suprailiac	6.5±2.2	12.1±5.8	14.4±6.3	M<J **
Thigh	9.8±3.9	14.1±6.4	14.4±4.9	M<S **

(1) ** $p < 0.01$; *** $p < 0.001$

TABLE F. Metabolic energy cost, M (watts) and (kcal · hr^{-1}) at rest and during exercise. Values determined by metabolic rate equation (c.f. equation p. 18).

Where: M = minutes during exercise

End = the end of exercise

( ) = kcal values

TABLE F

Metabolic Energy Cost, M (Watts and (kcal · hr^{-1})

Time	Marathoners	Joggers	Sedentary
Rest	102	115	117
	(88)[a]	(98)	(101)
5M	711	796	813
	(612)	(685)	(700)
10M	1539	1724	1767
	(1324)	(1484)	(1521)
End	2480	2305	1760
	(2135)	(1984)	(1515)

[a] 1.162 watts = 1 kcal/hr

DISCUSSION

Subjects

In choosing subjects for this study, a special effort was made to match groups by physical characteristics. It was difficult to find sedentary men who were healthy, nonsmokers and were also lean. It was also difficult to find highly conditioned runners with greater than 10 percent body fat. Therefore, although sedentary subjects and joggers were comparable in percent fat and body weight, marathoners had significantly lower body fat and body weight. The lower percent body fat and body weight, as well as the higher $\dot{V}O_2max$, is undoubtably related to exercise training. Body fat, body weight, and $\dot{V}O_2max$ were all related to temperature responses in our subjects. This is consistent with previous reports[6,20,87,103] that a decreased percent body fat, decreased body weight, and increased $\dot{V}O_2max$ in conditioned subjects are related to improved heat dissipation.

The total energy costs, i.e. the metabolic costs, of exercise on a treadmill can be calculated using a metabolic rate equation which gives energy cost in watts during work.[35,36]

$$1.5 \times wt + 1.5\ wt\ (velocity^2 \times 0.35\ Velocity \cdot Grade)$$

This equation is a linear function of body weight (wt) and, thus, when used to calculate energy costs of exercise of these subjects on the Bruce protocol, it differentiates between the groups (Table F). Because the marathoners had a lower body weight (although their heights were comparable to heights of the other groups), they had energy expenditures that were only slightly higher than those of the joggers at end exercise. The maximum oxygen

consumption also clearly reflects the differences between the groups. However, when $\dot{V}O_2max$ is expressed in total ml of O_2 per minute (see Table 2) the differences (expressed as percent; M>J 12.8%, M>S 23.3%, J>S 12.0%) are less striking than when expressed in ml O_2 per kg per minute (M>J 23.3%, M>S 33.1%, J>S 12.8%). The former values for $\dot{V}O_2max$ (ml · min^{-1}) give a better representation of the increase in aerobic capacity that occurs with training because they are not influenced by weight loss which also often occurs with training.[96]

Rectal Temperature (T_{re})

The rectal temperature (T_{re}) response of subjects to the short-term (transient) acute work used in this study resembles the reported T_{re} response seen in subjects exposed to long-term steady-state work in a heated environment.[3,6,10,36] The T_{re} response of better conditioned subjects also resembles the reported T_{re} response seen in environmentally heat acclimated subjects.[34,37,76] The finding that T_{re} is lower in better conditioned individuals for any given workload is consistent with previous observations.[77] However, Strydom et al.[92] criticized similar work on the grounds that the lesser T_{re} response was due to lower body weight and, therefore, a lower metabolic rate (heat production) at a given workload in better-conditioned individuals.

Reports by Åstrand[4] and Saltin and Hermansen[87] suggest that T_{re} rather than being solely related to absolute metabolic rate, is also closely related to the individuals' relative metabolic rate, i.e., the percent of $\dot{V}O_2max$ that a given metabolic rate represents. As the percent of $\dot{V}O_2max$ that a given $\dot{V}O_2$ represents increases during work, T_{re} increases correspondingly since more of the cardiac output

is required to deliver oxygen to the working muscles; thus increased demand for cardiac output should also have an effect on skin temperature. Therefore, a lower percent of $\dot{V}O_2max$ at a given workload corresponds to a lower T_{re}. A better conditioned individual with a higher $\dot{V}O_2max$ requires a smaller percent of his max to perform a given workload, therefore his T_{re} is lower at that workload than a less conditioned individual. The fact that the marathoners had a greater $\dot{V}O_2$ than the joggers or sedentary groups at each time point only reflects that the marathoners derived more of the total energy production from aerobic means than from anaerobic means. Data in this study show a consistent inverse relationship between T_{re} and $\dot{V}O_2max$ at each time point during exercise (Table A). This is in agreement with similar findings discussed by Wyndham.[98]

An additional argument against the simplistic lower weight explanation is that joggers were not significantly different in body weight from the sedentary group, and thus had a similar absolute heat production. However, they did have a significantly higher $\dot{V}O_2max$ and therefore used a lower percent of that maximum at a given workload (i.e. had a lower relative heat production). Therefore, their T_{re} could be maintained at a significantly lower level than the sedentary group during exercise. However, as the joggers approached 70% of their $\dot{V}O_2max$, their rate of heat accumulation appeared to increase rapidly and resembled the sedentary group; at the same point in time, the marathoners' rate of heat accumulation was still minimal because they were only at about 40-45% of their $\dot{V}O_2max$ as an effect of both their lower heat production (i.e. weight) and higher $\dot{V}O_2max$ (i.e. physical conditioning) (see Figure 2). This suggests that joggers

lack comparable heat dissipation capacity compared with marathoners. The conclusion drawn is that joggers and marathoners acquire through conditioning a means to maintain a lower T_{re} for a given heat load during acute short-term exercise in comparison to the sedentary group. However, joggers were not as adequately conditioned (i.e. they had a higher relative workload) and thus experienced a more significant heat accumulation than the marathoners.

It appears, in view of the five minute lag time in T_{re} response to exercise, that internal body heat increases at about the same time during exercise in each of the three groups. The magnitude of response and rate of rise of T_{re} is dependent on both the absolute and the relative workload as well as on the rate of heat dissipation. While the lighter body weight of the marathoners would result in a lower heat production at a given point in time, their total heat production during exercise was greater (longer treadmill time). This would explain the higher peak temperature and higher temperature during most of the recovery period seen in marathoners. The significant increase (overshoot) in T_{re} in each group during the first few minutes of recovery also expresses the lag period of transfer of heat from the working muscle to the rectum during exercise.[60]

Skin Temperature (T_{sk})

Skin temperature responses generally vary according to the level of physical condition of the individual. The decrease in skin temperature generally reflects either decreased skin blood flow or increased skin cooling due to evaporation of sweat. Early in exercise skin temperatures are primarily affected by skin blood flow since

sweating is not significant; vasoconstrictor reflex activity shunts blood away from the skin and to the working muscles during exercise and thus decreases skin temperature.[12] An increase in skin temperature indicates primarily enhanced skin blood flow. With cessation of exercise, vasoconstrictor activity decreases as the demand for blood to the working muscles decreases. Blood flow is then diverted back to the skin for cooling and thus skin temperature rises. Assumption of the supine posture after exercise also decreases the vasoconstrictor reflex.[61]

The decrease in skin temperature after an initial peak during the first half of recovery in many of the skin sites is probably due to increased sweating activity stimulated by the increased internal and skin temperature. In contrast to a notable absence of visible sweating during exercise, extensive sweating was noticeable in many subjects within the first few minutes of recovery, presumably as a result of the loss of the effective air motion generated during exercise in combination with the increase in skin temperature on cessation of exercise. As T_{re} fell below 37.2°C, sweating decreased.

Forehead Skin Temperature

The forehead skin temperature response to exercise and recovery is unique in three major ways. First, the forehead has very little vasoconstrictor activity.[52] Therefore, forehead skin blood flow would be expected to show little decrease with acute exercise. This is consistent with the observation that forehead skin temperatures did not decrease with exercise. Second, the forehead has a greater

number of warm skin receptors than other areas of the body.[67] Thus, when vasoconstrictor activity decreases after exercise, vasodilation is enhanced. This is consistent with the significantly greater increase in forehead temperature after exercise when compared with most other skin sites. Third, the forehead sweats more profusely than other areas of the body.[64] The significant fall in temperature after the early recovery peak in all three groups may be related to this third feature since earlier, more profuse sweating by the forehead would account for the greater fall in its temperature during the first half of recovery. The lack of differences in these responses between the groups indicates that forehead temperature response is not affected by physical conditioning.

Chest Skin Temperature

The lack of any significant change in temperature during exercise could indicate a limited vasoconstrictor reflex in the chest during exercise. The chest seems to have an increased skin blood flow during the first few minutes of recovery, but the temperature increase is not of the magnitude seen in the forehead. The lack of a significant decline in temperature in the joggers and sedentary group following the peak temperature and the higher temperature in the marathoners at 50 minutes after exercise may be related to a more rapid transfer of heat from their core because of decreased subcutaneous fat stores. Decreased subcutaneous fat thickness will enhance non-evaporative heat loss.[53] This is consistent with the

inverse correlation found in this study between chest skin temperature and body fat (Table C).

Abdomen Skin Temperature

An inverse correlation was also found between abdomen skin temperature and body fat. Marathoners, with the least abdominal skinfold thickness and body fat, exhibited higher abdomen skin temperature during exercise and the first part of recovery than the joggers or sedentary groups; their increased thermal gradient between the muscles and skin may also have modified their sweat gland activity.[20] In other words, the decreased transfer of heat through the subcutaneous fat to the skin reduced sweating. This could explain the minimal decline in temperature from the early recovery peak in the joggers and sedentary groups.

The lack of a significant change in abdomen skin temperature in the marathoners during exercise until the end of exercise, is consistent with what is known about the effects of conditioning on vasomotor constrictor activity.[23] The vasomotor constrictor activity varies according to relative intensity of exercise. With improved conditioning, heart rate and vasomotor constrictor activity are lower for any given level of submaximal exercise.

Forearm and Hand Skin Temperatures

Forearm and hand skin temperatures responded similarly with exercise and recovery. They were the coldest sites evaluated. Compared to other body regions they have a greater surface area to mass ratio and, therefore, non-evaporative heat loss should be greater

in these regions. The vasoconstriction reflex in the forearm and hand during exercise are known to be greater than in other area of the body.[13] Hand skin temperatures were significantly lower in the better conditioned individuals.

In the hand, as in the abdomen, the skin temperature response of the sedentary group suggests a greater early vasoconstrictor outflow (R-10), probably because of a greater requirement for internal blood flow (higher relative workload). Why this is not reflected in the forearm is unknown. However, there have been reports[1,56] that the hand is more responsive to thermal inputs and other vasodilation drives than other regions of the body. Additionally, well conditioned and heat acclimated individuals have lower thresholds for vasodilator activity.

During recovery, heat dissipation should be occurring in both the forearm and hand. Lack of significant rise in forearm temperature during the first half of recovery suggests that heat is being dissipated during recovery, most likely by evaporation of sweat. When the sweating stimulus (T_{re}) reaches its lower range (37.2 °C), forearm skin temperature increases significantly to its plateau temperature. This pattern is not seen in the hand.

Data in this study indicates that the hand has better heat dissipation than the forearm during exercise but not during recovery. This is not consistent with earlier literature.[66,79] The lack of a significant increase in hand temperature during the first few minutes of recovery would indicate a possible delayed vasodilator activity in all groups.

Thigh Skin Temperature

Initially with exercise, the vasoconstrictor reflex appears to decrease the skin temperature in the thigh as it did at other skin sites. However, since the thigh is one of the major working muscle groups during running, a large thermal load must be generated in this area. With a large thermal load, thermal sensitive vasodilation activity and subcutaneous shunting should begin sooner. This would explain the decrease in the amount of thigh skin temperature drop as exercise continued. As seen in the hand and abdomen, the vasodilator activity appears to be enhanced in the better conditioned groups, especially in the marathoners. Temperature responses during recovery in the thigh resemble those seen in the abdomen. The significant increase in temperature during the first few minutes of recovery resemble some of the other skin sites' activity, but the heat dissipation activity is blunted. The skinfold thickness of the thigh, as for the chest and abdomen, is also large compared to a number of the other areas measured. Sweating may also be decreased in the thigh since as Nadel[64] showed, the thermal sensitivity coefficients of the chest, abdomen, and thigh are reduced as compared to the forehead. Newburgh's[66] review of Krause, Kuno, and Randall's work further emphasized the reduced sweating activity in these skin areas. Therefore, the apparent lack of heat dissipation in the thigh during recovery could be a combination of 1) a high thermal load 2) a large amount of subcutaneous tissue, and 3) limited sweating activity. The fact that the marathoners had a significant decline in temperature during the first half of recovery as compared to the other groups may

indicate that the sweating activity that is present is greater in the better conditioned individuals, as noted for other skin regions.

Calf Skin Temperature

The calf skin site was the only skin site in each group to show an increase in temperature during exercise. In a walking/running exercise that uses a inclined treadmill, the calf muscle would be expected to be the major working muscle. The subcutaneous fat of the calf, although not measured in this study, is small. These two factors and the finding that calf temperature is related to $\dot{V}O_2max$ at each time point would explain the increase in temperature during exercise. The significant increase in temperature for the sedentary group during the first five minutes of exercise again may represent a greater relative amount of work (i.e. % $\dot{V}O_2max$) in comparison to the other two groups.

Nadel[64] and Newburgh[66] reported that the calf's sweat gland numbers and thermal sensitivity are reduced as compared to other areas of the body, as are the thigh's. However, the finding of a significant decrease in temperature during the first half of recovery would suggest otherwise. Possibly, the reduced subcutaneous fat may allow a better reflection of the heat dissipation activity. The significant increase in temperature the first few minutes of recovery in the marathoners and joggers most probably reflects the higher accumulation of heat due to the longer treadmill times. The decrease in temperature to a comparable level with the sedentary group within 15 minutes post exercise

reflects an enhanced heat dissipation activity in the marathoners and joggers. The marathoners reached their post exercise plateau by the end of the first half of recovery. The joggers and sedentary subjects, on the other hand, had calf temperatures that continued to decline to reach a comparable level during the second half of recovery. This seems to indicate an even greater heat dissipation activity in the marathoners.

Scapula and Lumbar Skin Temperatures

Data for the scapula and lumbar regions were recorded only during exercise because during recovery the subjects while recumbent were laying on the thermistors. This eliminated any further recording of natural recovery skin temperature in those two areas. Unless the subjects were required to stand during the one hour recovery period, it would have been difficult to record temperature in these areas any other way. Olsen and Fanger[74] reported using a chair with plastic strips to reduce this influence on the person's heat loss to the environment. The possibility of using a similar apparatus in future studies is worth considering.

The significant decrease in temperature in the scapula region during exercise would indicate pronounced vasomotor constrictor activity similar to that seen in other regions; the lumbar region seems to exhibit no vasomotor constrictor activity. Similar findings in the lumbar region have not been reported before. It is apparent that the thermal responses of the upper and lower posterior torso regions are not comparable with the thermal responses of the upper and lower anterior torso regions. Without recovery temperatures to

analyze, it is difficult to discern any effect of conditioning for these anatomical sites.

Findings in this study have shown that during acute short-term exercise in a thermoneutral environment the skin temperatures among the different body regions vary considerably, reflecting differences in perfusion, subcutaneous fat, sweating and convection. Also, the skin thermal responses vary considerably among groups of individuals with different levels of conditioning. Before this study began it was suspected that some changes and such differences would occur. It was also felt that use of mathematical formulae to express thermal responses in terms of mean body temperatures as heat storage and especially those lumping individual skin temperatures into a single mean skin temperature ($\bar{T}_{sk}$), and the further complication of the use of a number of different formulae for mean skin temperature, would obscure these changes and differences. The following discussion of the analysis conducted during this study on the various mathematical formulae used to express thermal response, confirms these suspicions.

Mathematical Formulae

Mean Skin Temperature ($\bar{T}_{sk}$)

Goldman's[40] presentation of the relationships between different mean weighted skin temperatures acknowledged that statistical significant differences could be established. However, he felt that when the distribution of temperature over the body was not of primary interest, the values of MWST were acceptable. The reverse of this, in part, is the point that is presented in this comparison study. Skin temperature is affected by a variety of variables; for example,

by underlying muscle activity, vascularization, skin blood flow, subcutaneous tissue amount, environmental conditions, sweating activity, and the state of physical conditioning to name but a few. Thermal and sweating sensitivity is unevenly distributed in the human skin. The present findings, demonstrating that the thermal and sweating sensitivity are also affected at different skin sites by physical conditioning, increases the complexity of characterizing skin thermal responses. It is contended that in order to best identify the skin thermal responses in a man exposed to a given heat load, his level of conditioning must be recognized and a variety of individual skin sites must be monitored. Use of such mathematical formulae as mean weighted skin temperature and arithmetic mean values obscure valuable information. Findings during this study indicate that the statistically significant differences between the various MWST formulae, and between the MWST and arithmetic $\bar{T}_{sk}$ formulae should be a primary concern. It appears that the skin sites chosen for use in the weighted formulae may, themselves, be causing significant differences. In the M_3WST formula (equation 4d) one of the three skin sites used, the chest, is weighted 50 percent. In the M_4WST (equation 4c) the chest is weighted 34 percent. Figure 12 (M_3WST) and Figure 13 (M_4WST) can be seen to look like Figure 4 (chest). Even though individual skin sites are being weighted to equal a total surface area of one (1.00), weighting one site with such a large percentage is going to weight the results toward that particular sites' thermal activity. The uniqueness of M_3WST during exercise, showing an increase in temperature where others did not change, or decreased, can be explained by the use of the calf skin site which is weighted

36 percent in the formula. Analysis of the individual skin sites' data revealed the calf to be the only skin site with an increase in temperature during exercise (Figure 9).

The arithmetic means not only fail to represent the individual skin sites accurately, but they are significantly different from the MWST formulas. Lack of proportionality to the skin sites surface area would contribute to this difference. Increasing the number of skin sites as Hardy and Dubois[49] did, would still not prevent some representation of the most weighted area's thermal response, probably the chest since its surface area will always be the largest.

To continue the comparison study further, three related mean body temperature formulae ($\bar{T}_b$) (equations 5a, 5b, and 5c) were evaluated. Since the value of $\bar{T}_b$ consists of one third of the $\bar{T}_{sk}$ value it was felt that $\bar{T}_b$ would be inadequate to identify properly the thermal responses of the different conditioned groups of subjects. Although not completely consistent with the differences found between groups and between equations using different $\bar{T}_{sk}$ formulae, it was not surprising to find significant differences using the different $\bar{T}_b$ formulae. As early as 1947, Winslow and Gagge[98] reported concerns for the validity of $\bar{T}_b$ when the body was exposed to a vasoconstricting stimulus. They were referring to a cool environment, but the vasoconstrictor reflex in exercise may also affect its validity.

Since $\bar{T}_b$ misses the more subtle, skin area specific, thermal responses, it was anticipated that the body heat storage and change in body heat content (equations 7a, 7b, 7c) would have a similar problem and this proved to be the case (Tables 42-47, and Figures 19-21). Body heat storage (S) does present (especially graphically) an over-

all representation of when body heat was changing the most. The accuracy per group, because of the $\bar{T}_b$ use, is questionable. However, it provides us with "general" information that 1) total body heat and its change is minimal during acute short-term exercise, 2) there is an apparent marked increase in body heat during the first few minutes of recovery, 3) there is a marked decrease in body heat during recovery and 4) body heat is still markedly elevated even after one hour of recovery in all subjects. This is consistent with the overall results of T_{re} and individual T_{sk} responses.

At the beginning of this study it was felt that if $\bar{T}_{sk}$ could be used accurately to characterize the thermal responses in different groups of subjects at all, it would be in the heat gradient equation (H_{grad}) (equations 6a, 6b, and 6c). The principle of a heat gradient equation is that the difference in temperature between T_{re} and $\bar{T}_{sk}$ would give an indication of heat dissipation activity. Since heat dissipation is affected by the level of physical conditioning, H_{grad} should reflect the level of conditioning. As body heat accumulates, skin blood flow increases, thereby presenting a higher $\bar{T}_{sk}$ which would produce a smaller H_{grad}. The enhanced skin perfusion would allow an increase in heat loss and thereby reduce T_{re}. However, data indicate that group differentiation was generally not demonstrated (see Tables 48 to 53). The individual T_{re} and T_{sk} suggest that more differentiation should have been present. Therefore, H_{grad} is probably not a good indicator of such complex thermal responses.

The conclusion from this comparison study of the different mathematical formulae is that they cannot adequately discribe the thermal responses of individuals during an acute short-term exercise

stress in a thermoneutral environment. The validity of any of these formulae is questionable because of their marked differences in characterizing a single state. The thermal responses of men with different levels of conditioning are extremely variable within each group and, indeed, within each individual as evidenced by the varying responses of the different skin sites. An attempt to use a given temperature variable or combination of them to identify accurately a "true" thermal response is misleading. A variety of thermal variables must be monitored and addressed and then a combination of the results may be used to accurately express that individual's thermal state.

Statistical Procedures

Despite the statistical significance of many of the Pearson Correlation Coefficient Analysis in this study, the relative strength of the relationship (i.e., r^2) were generally quite low, e.g., an r value of 0.5 when attempting to identify the relationship of $\dot{V}O_2max$ and T_{re} would imply that the $\dot{V}O_2max$ could only explain 25% (0.5^2) of the associated temperature response, leaving the other 75% to be accounted for by other factors. Considering the multiple causes of large variability in human subjects, including inherent error, experimental error, and the small sample size, a 0.3 to 0.6 correlation was considered to be of practical importance. The expressed p-value defines the probability that one would observe a correlation as large or larger than the one that was observed if the true correlation was "0." In other words, a significant p-value indicates that the variables are not statistically independent and therefore the two variables are related. Correlations which were

consistent at a majority of the time points analyzed and had a value of $p < 0.05$, indicating a dependency of the variables, were considered to show a pattern of notable importance. Correlation coefficients with probability (p) less than 0.05 were considered statistically significant regardless of whether the coefficient of determination (r^2) indicates that the correlation accounted for only 4% of the relationship (i.e., $r = 0.2$) or 90% ($r = 0.95$).

SUMMARY AND CONCLUSION

This study shows that with an acute (non-steady state) exercise-induced heat load in a comfortable thermoneutral environment, the body temperature changes of men with different levels of physical fitness as a result of conditioning are different (see Figure 22).

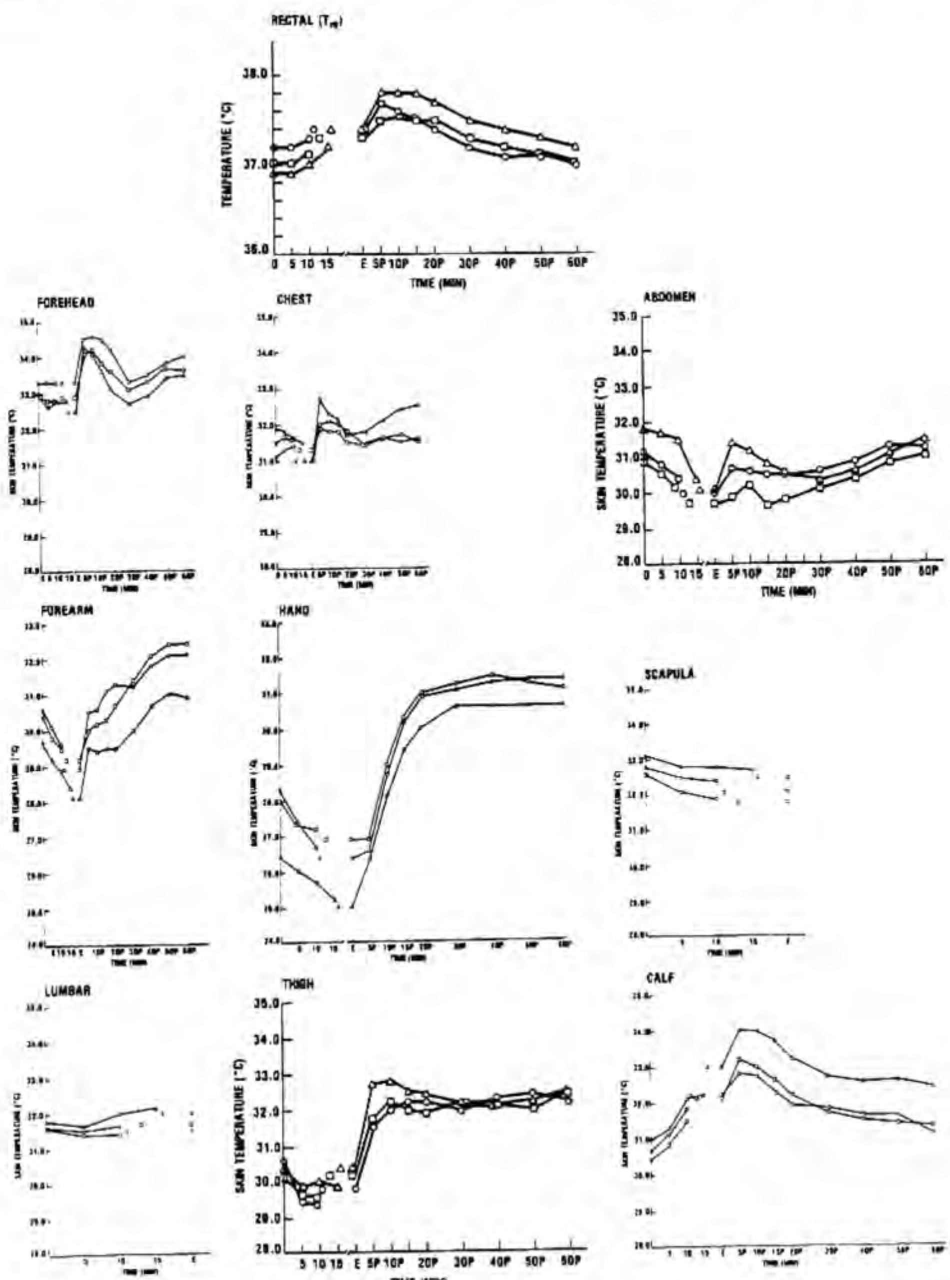


FIGURE 22

The rectal temperature (T_{re}) responses to exercise in the three groups of subjects resemble the reported temperature responses of individuals exposed to long-term steady state work in a heated environment. With exercise, T_{re} increases, peaks within a few minutes of recovery, and then slowly decreases during a one hour recovery period. The better conditioned groups, the marathoners, had T_{re} responses similar to those reported of individuals that are environmentally heat acclimated.

Skin temperature responses of subject groups varied during exercise and recovery. Physical condition status seems to affect each skin site except for the forehead. The thermal responses of the skin sites suggest that better conditioned individuals dissipate heat better. This may be related to increased skin blood flow, increased sweating activity, and/or decreased insulation from the inner body with less subcutaneous fat.

The relationship of body temperature with $\dot{V}O_2$max and percent body fat appears to be quite significant in the study. Highly conditioned subjects had both high maximum oxygen consumption and low body fat. The higher the $\dot{V}O_2$max, the lower the T_{re} maintained during exercise. Even though the better level of conditioning allows for a greater work time, the increased total heat load accumulated is dissipated at a greater rate than in less fit indviduals. A larger percent of body fat appears to blunt the thermal responses of the skin and increased subcutaneous fat reduces heat dissipation. This effect is most pronounced in the chest and abdominal regions where skinfold thickness was greatest.

Although some of the T_{re} and T_{sk} responses of the moderate conditioned group (joggers) in this study resembled the well-conditioned group (marathoners), overall they resembled the sedentary group in thermal response. With few exceptions, all significant differences between the groups in thermal response were seen between the marathoners and joggers or between the marathoners and the sedentary group. There was minimal difference between the joggers and the sedentary group.

While energy cost and heat production are directly related to workload, and are minimally influenced by level of physical training, the ability to dissipate heat is clearly related to physical conditioning. This study has added support to the finding that non environmentally heat acclimated individuals who are well-conditioned have temperature responses resembling those who are environmentally heat acclimated. This study has identified that conditioning affects the temperature response of different skin regions differently and the pattern is different in less conditioned individuals. This is missed when using mathematical formulae derived for the purpose of identifying a mean skin temperature ($\bar{T}_{sk}$) and a mean total body temperature ($\bar{T}_b$). An accurate appraisal of an individual's thermal response and his level of conditioning can be used to predict his resistence to heat stress. This could be of significant value in assessing individuals for sports, industry, and military operations.

APPENDIX 1. Volunteer Agreement (consent form).

APPENDIX 1

VOLUNTEER AGREEMENT - Homeostatic and Hematologic Alterations with Exercise (laboratory studies)

This study is designed to assess blood clotting and other changes in the blood and blood elements with exercise and physical conditioning. These changes will be compared with changes in the cardiovascular (heart) and respiratory (breathing) systems and in the body's ability to handle heat stress with exercise and physical conditioning.

We will check blood samples before, during, and after exercise (total of 3 or 4 samples times). Not more than 50 ml (about 3 tablespoons) of blood will be drawn from a vein in your arm during each sample period. This may cause some discomfort or bruising of your arm. You will be exercised on a treadmill or bicycle ergometer (stationary bicycle). The duration of exercise will probably be between 15 and 45 minutes depending on your degree of physical conditioning.

You will be given a medical evaluation before entering this study. You will be watched during exercise and a physician will be in attendance. Your heart rate and blood pressure will be recorded during exercise. Your body temperature will be monitored by thermistors (small instruments used to measure temperature) taped to your body, a thermistor in your rectum and a thermistor in one ear. You will be breathing into a machine which will analyze oxygen consumption and other changes with exercise.

DoD will provide medical care for DoD eligibles (active duty, dependents, and retired military) for physical injury or illness resulting from pariticipation in this research. Such care may not be available to other research participants. Compensation may be available through judicial avenues to non-active duty research participants if they are injured through negligence (fault) of the Government.

If you believe that you have suffered any injury or illness as the result of participating in this research, please contact the Office of Grants Management, 295-3303, at the University. This office can review the matter with you and may be able to identify resources available from the University's Legal Counsel, 295-3028.

Your name will not be used in the publication of this data, nor will your personal data be released without your consent.

The testing procedures have been reviewed by ______________________ and all my questions about the study have been satisfactorily answered. I understand the nature of this experiment and volunteer to participate in it. While the study is designed for research purposes and not to directly benefit me, I understand that some of the information may be of interest and medical significance to me. If I have any additional questions, I understand that I may contact Dr. Earl Ferguson at the Uniformed Services University of the Health Sciences, Bethesda, Maryland and he will discuss the study and the results of my tests with me.

It is my understanding that I may withdraw my consent to participate in this study at any time without prejudice to future contacts with USUHS.

PRINTED NAME ______________________________

SIGNATURE ________________________________

WITNESS ____________________________

DATE ______________________________

APPENDIX 2. Months of the year in which subjects were tested.

APPENDIX 2

Month of Testing

Date	Marathoners	Joggers	Sedentary
Jan	1	0	0
Feb	2	0	0
Mar	1	2	0
Apr	0	3	1
May	0	0	0
Jun	0	2	2
Jul	5	4	1
Aug	0	0	0
Sep	2	5	3
Oct	3	3	4
Nov	2	0	4
Dec	0	0	0

APPENDIX 3. Report of Medical History, Standard Form 93.
Completed by all subjects at physical examination
prior to exercise testing.

REPORT OF MEDICAL HISTORY

(THIS INFORMATION IS FOR OFFICIAL AND MEDICALLY-CONFIDENTIAL USE ONLY AND WILL NOT BE RELEASED TO UNAUTHORIZED PERSONS)

1. LAST NAME—FIRST NAME—MIDDLE NAME		2. SOCIAL SECURITY OR IDENTIFICATION NO.
3. HOME ADDRESS *(No. street or RFD, city or town, State, and ZIP CODE)*		4. POSITION *(title, grade, component)*
5. PURPOSE OF EXAMINATION	6. DATE OF EXAMINATION	7. EXAMINING FACILITY OR EXAMINER, AND ADDRESS *(Include ZIP Code)*

8. STATEMENT OF EXAMINEE'S PRESENT HEALTH AND MEDICATIONS CURRENTLY USED *(Follow by description of past history, if complaint exists)*

9. HAVE YOU EVER *(Please check each item)*

YES	NO	*(Check each item)*
		Lived with anyone who had tuberculosis
		Coughed up blood
		Bled excessively after injury or tooth extraction
		Attempted suicide
		Been a sleepwalker

10. DO YOU *(Please check each item)*

YES	NO	*(Check each item)*
		Wear glasses or contact lenses
		Have vision in both eyes
		Wear a hearing aid
		Stutter or stammer habitually
		Wear a brace or back support

11. HAVE YOU EVER HAD OR HAVE YOU NOW *(Please check at left of each item)*

YES	NO	DON'T KNOW	*(Check each item)*	YES	NO	DON'T KNOW	*(Check each item)*	YES	NO	DON'T KNOW	*(Check each item)*
			Scarlet fever, erysipelas				Cramps in your legs				"Trick" or locked knee
			Rheumatic fever				Frequent indigestion				Foot trouble
			Swollen or painful joints				Stomach, liver, or intestinal trouble				Neuritis
			Frequent or severe headache				Gall bladder trouble or gallstones				Paralysis (include infantile)
			Dizziness or fainting spells				Jaundice or hepatitis				Epilepsy or fits
			Eye trouble				Adverse reaction to serum, drug, or medicine				Car, train, sea or air sickness
			Ear, nose, or throat trouble								Frequent trouble sleeping
			Hearing loss				Broken bones				Depression or excessive worry
			Chronic or frequent colds				Tumor, growth, cyst, cancer				Loss of memory or amnesia
			Severe tooth or gum trouble				Rupture/hernia				Nervous trouble of any sort
			Sinusitis				Piles or rectal disease				Periods of unconsciousness
			Hay Fever				Frequent or painful urination				
			Head injury				Bed wetting since age 12				
			Skin diseases				Kidney stone or blood in urine				
			Thyroid trouble				Sugar or albumin in urine				
			Tuberculosis				VD—Syphilis, gonorrhea, etc.				
			Asthma				Recent gain or loss of weight				
			Shortness of breath				Arthritis, Rheumatism, or Bursitis				
			Pain or pressure in chest				Bone, joint or other deformity				
			Chronic cough				Lameness				
			Palpitation or pounding heart				Loss of finger or toe				
			Heart trouble				Painful or "trick" shoulder or elbow				
			High or low blood pressure				Recurrent back pain				

12. FEMALES ONLY: HAVE YOU EVER

YES	NO	DON'T KNOW	*(Check each item)*
			Been treated for a female disorder
			Had a change in menstrual pattern

13. WHAT IS YOUR USUAL OCCUPATION?

14. ARE YOU (Check one)

☐ Right handed ☐ Left handed

YES	NO	C[illegible]D. EVERY ITEM CHECKED YES MUST BE FULLY EXPLAINED IN BLANK SPACE ON RIGHT	
		15. Have you been refused employment or been unable to hold a job or stay in school because of: A. Sensitivity to chemicals, dust, sunlight, etc.	
		B. Inability to perform certain motions.	
		C. Inability to assume certain positions.	
		D. Other medical reasons *(If yes, give reasons.)*	
		16. Have you ever been treated for a mental condition? *(If yes, specify when, where, and give details).*	
		17. Have you ever been denied life insurance? *(If yes, state reason and give details.)*	
		18. Have you had, or have you been advised to have, any operations? *(If yes, describe and give age at which occurred.)*	
		19. Have you ever been a patient in any type of hospitals? *(If yes, specify when, where, why, and name of doctor and complete address of hospital.)*	
		20. Have you ever had any illness or injury other than those already noted? *(If yes, specify when, where, and give details.)*	
		21. Have you consulted or been treated by clinics, physicians, healers, or other practitioners within the past 5 years for other than minor illnesses? *(If yes, give complete address of doctor, hospital, clinic, and details.)*	
		22. Have you ever been rejected for military service because of physical, mental, or other reasons? *(If yes, give date and reason for rejection.)*	
		23. Have you ever been discharged from military service because of physical, mental, or other reasons? *(If yes, give date, reason, and type of discharge: whether honorable, other than honorable, for unfitness or unsuitability.)*	
		24. Have you ever received, is there pending, or have you applied for pension or compensation for existing disability? *(If yes, specify what kind, granted by whom, and what amount, when, why.)*	

I certify that I have reviewed the foregoing information supplied by me and that it is true and complete to the best of my knowledge.
I authorize any of the doctors, hospitals, or clinics mentioned above to furnish the Government a complete transcript of my medical record for purposes of processing my application for this employment or service.

TYPED OR PRINTED NAME OF EXAMINEE	SIGNATURE

NOTE: HAND TO THE DOCTOR OR NURSE, OR IF MAILED MARK ENVELOPE "TO BE OPENED BY MEDICAL OFFICER ONLY."

25. *Physician's summary and elaboration of all pertinent data (Physician shall comment on all positive answers in items 9 through 24. Physician may develop by interview any additional medical history he deems important, and record any significant findings here.)*

TYPED OR PRINTED NAME OF PHYSICIAN OR EXAMINER	DATE	SIGNATURE	NUMBER OF ATTACHED SHEETS

APPENDIX 4. Report of Medical Examination, Standard Form 88. Completed by examining physician on all subjects prior to exercise testing.

Standard Form 88
Revised 10/75
General Services Administration
Interagency Comm. on Medical Records
FPMR 101-11.806-8

REPORT OF MEDICAL EXAMINATION

1. LAST NAME—FIRST NAME—MIDDLE NAME	2. GRADE AND COMPONENT OR POSITION	3. IDENTIFICATION NO.
4. HOME ADDRESS (*Number, street or RFD, city or town, State and ZIP Code*)	5. PURPOSE OF EXAMINATION	6. DATE OF EXAMINATION

7. SEX	8. RACE	9. TOTAL YEARS GOVERNMENT SERVICE		10. AGENCY	11. ORGANIZATION UNIT
		MILITARY	CIVILIAN		

12. DATE OF BIRTH	13. PLACE OF BIRTH	14. NAME, RELATIONSHIP, AND ADDRESS OF NEXT OF KIN

15. EXAMINING FACILITY OR EXAMINER, AND ADDRESS	16. OTHER INFORMATION	
17. RATING OR SPECIALTY	TIME IN THIS CAPACITY (*Total*)	LAST SIX MONTHS

CLINICAL EVALUATION

NORMAL	(*Check each item in appropriate column, enter "NE" if not evaluated.*)	ABNORMAL
	18. HEAD, FACE, NECK, AND SCALP	
	19. NOSE	
	20. SINUSES	
	21. MOUTH AND THROAT	
	22. EARS—GENERAL (*Int. & ext. canals; Auditory acuity under items 70 and 71*)	
	23. DRUMS (*Perforation*)	
	24. EYES—GENERAL (*Visual acuity and refraction under items 59, 60 and 67*)	
	25. OPHTHALMOSCOPIC	
	26. PUPILS (*Equality and reaction*)	
	27. OCULAR MOTILITY (*Associated parallel movements, nystagmus*)	
	28. LUNGS AND CHEST (*Include breasts*)	
	29. HEART (*Thrust, size, rhythm, sounds*)	
	30. VASCULAR SYSTEM (*Varicosities, etc.*)	
	31. ABDOMEN AND VISCERA (*Include hernia*)	
	32. ANUS AND RECTUM (*Hemorrhoids, fistulae; Prostate, if indicated*)	
	33. ENDOCRINE SYSTEM	
	34. G-U SYSTEM	
	35. UPPER EXTREMITIES (*Strength, range of motion*)	
	36. FEET	
	37. LOWER EXTREMITIES (*Except feet; Strength, range of motion*)	
	38. SPINE, OTHER MUSCULOSKELETAL	
	39. IDENTIFYING BODY MARKS, SCARS, TATTOOS	
	40. SKIN, LYMPHATICS	
	41. NEUROLOGIC (*Equilibrium tests under item 72*)	
	42. PSYCHIATRIC (*Specify any personality deviation*)	
	43. PELVIC (*Females only*) (*Check how done*) ☐ VAGINAL ☐ RECTAL	

NOTES (*Describe every abnormality in detail. Enter pertinent item number before each comment. Continue in item 73 and use additional sheets if necessary.*)

(Continue in item 73)

44. DENTAL (*Place appropriate symbols, shown in examples, above or below number of upper and lower teeth.*)

Restorable teeth — *Nonrestorable teeth* — *Missing teeth* — *Replaced by dentures* — *Fixed Partial dentures*

RIGHT	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	LEFT
	32	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	

REMARKS AND ADDITIONAL DENTAL DEFECTS AND DISEASES

LABORATORY FINDINGS

45. URINALYSIS A. SPECIFIC GRAVITY			46. CHEST X-RAY (*Place, date, film number and result*)
B. ALBUMIN	D. MICROSCOPIC		
C. SUGAR			
47. SEROLOGY (*Specify test used and result*)	48. EKG	49. BLOOD TYPE AND RH FACTOR	50. OTHER TESTS

88-118

MEASUREMENTS AND OTHER FINDINGS

51. HEIGHT	52. WEIGHT	53. COLOR HAIR	54. COLOR EYES	55. BUILD ☐ SLENDER ☐ MEDIUM ☐ HEAVY ☐ OBESE	56. TEMPERATURE

57. BLOOD PRESSURE (Arm at heart level)						58. PULSE (Arm at heart level)				
A. SITTING	SYS	B. RECUMBENT	SYS	C. STANDING (3 min.)	SYS	A. SITTING	B. AFTER EXERCISE	C. 2 MIN. AFTER	D. RECUMBENT	E. AFTER STANDING 3 MIN
	DIAS		DIAS		DIAS.					

59. DISTANT VISION		60. REFRACTION			61. NEAR VISION	
RIGHT 20/	CORR. TO 20/	BY	S.	CX	CORR. TO	BY
LEFT 20/	CORR. TO 20/	BY	S.	CX	CORR. TO	BY

62. HETEROPHORIA (Specify distance)

ES°	EX°	R. H.	L. H.	PRISM DIV.	PRISM CONV.	PC	PD
					CT		

63. ACCOMMODATION		64. COLOR VISION (Test used and result)	65. DEPTH PERCEPTION (Test used and score)	UNCORRECTED
RIGHT	LEFT			CORRECTED

66. FIELD OF VISION	67. NIGHT VISION (Test used and score)	68. RED LENS TEST	69. INTRAOCULAR TENSION

70. HEARING		71. AUDIOMETER									72. PSYCHOLOGICAL AND PSYCHOMOTOR (Tests used and score)
RIGHT WV /15	SV /15		250 256	500 512	1000 1024	2000 2048	3000 2896	4000 4096	6000 6144	8000 8192	
LEFT WV /15	SV /15	RIGHT									
		LEFT									

73. NOTES (Continued) AND SIGNIFICANT OR INTERVAL HISTORY

(Use additional sheets if necessary)

74. SUMMARY OF DEFECTS AND DIAGNOSES (List diagnoses with item numbers)

75. RECOMMENDATIONS—FURTHER SPECIALIST EXAMINATIONS INDICATED (Specify)

76. A. PHYSICAL PROFILE

P	U	L	H	E	S

77. EXAMINEE (Check)

A ☐ IS QUALIFIED FOR

B ☐ IS NOT QUALIFIED FOR

B. PHYSICAL CATEGORY

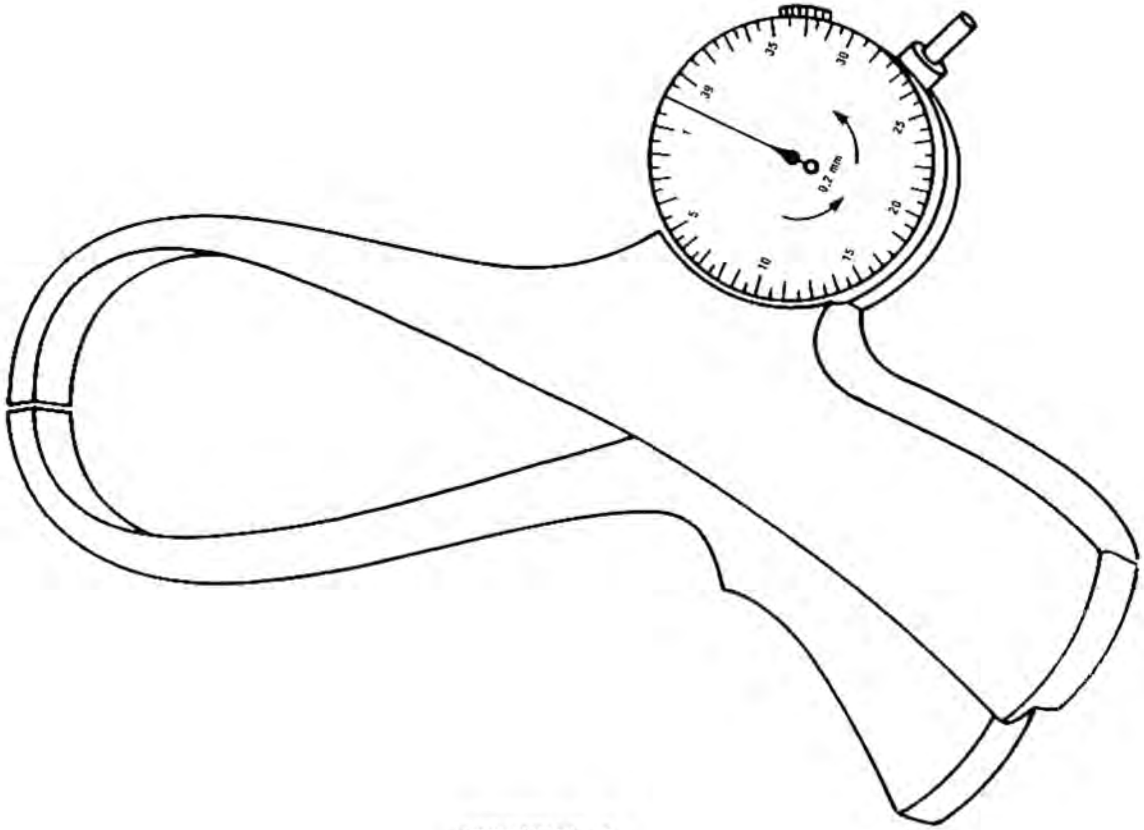
A	B	C	E

78. IF NOT QUALIFIED, LIST DISQUALIFYING DEFECTS BY ITEM NUMBER

79. TYPED OR PRINTED NAME OF PHYSICIAN	SIGNATURE
80. TYPED OR PRINTED NAME OF PHYSICIAN	SIGNATURE
81. TYPED OR PRINTED NAME OF DENTIST OR PHYSICIAN (Indicate which)	SIGNATURE
82. TYPED OR PRINTED NAME OF REVIEWING OFFICER OR APPROVING AUTHORITY	SIGNATURE / NUMBER OF ATTACHED SHEETS

U.S. GPO 1979-0-281-187/4265

APPENDIX 5. Harpenden Skinfold Caliper. Manufactured by Holtain Ltd. Crymych U.K. Read to 0.2 mm. Used in measuring selected skin sites for calculating percent body fat.



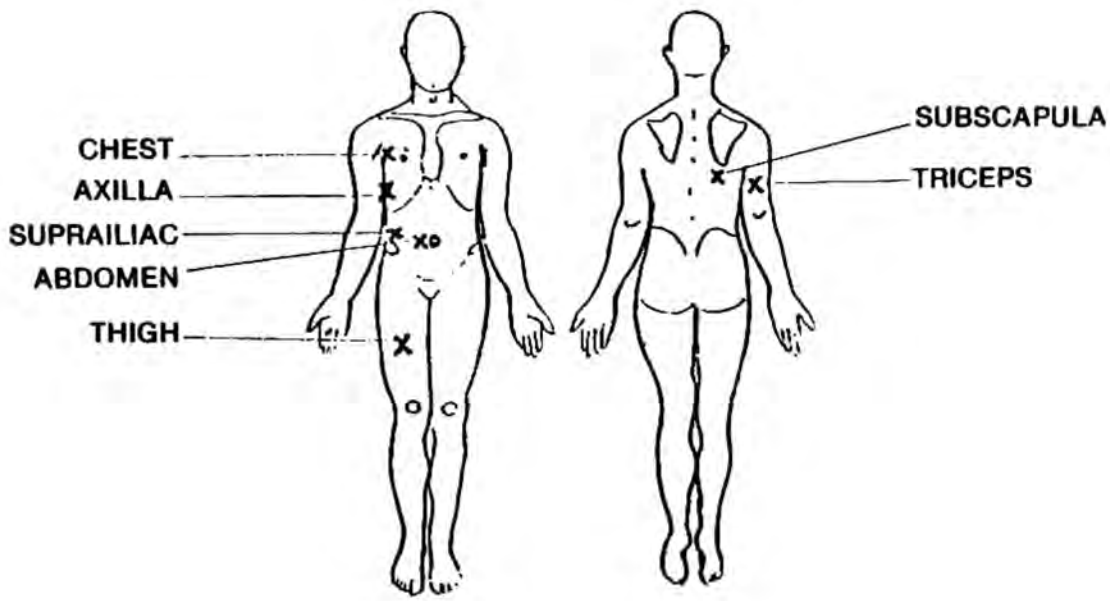
APPENDIX 5

APPENDIX 6. Skinfold measurement technique using skinfold caliper. Selected skinfold site depicted in this appendix is the triceps.

APPENDIX 6

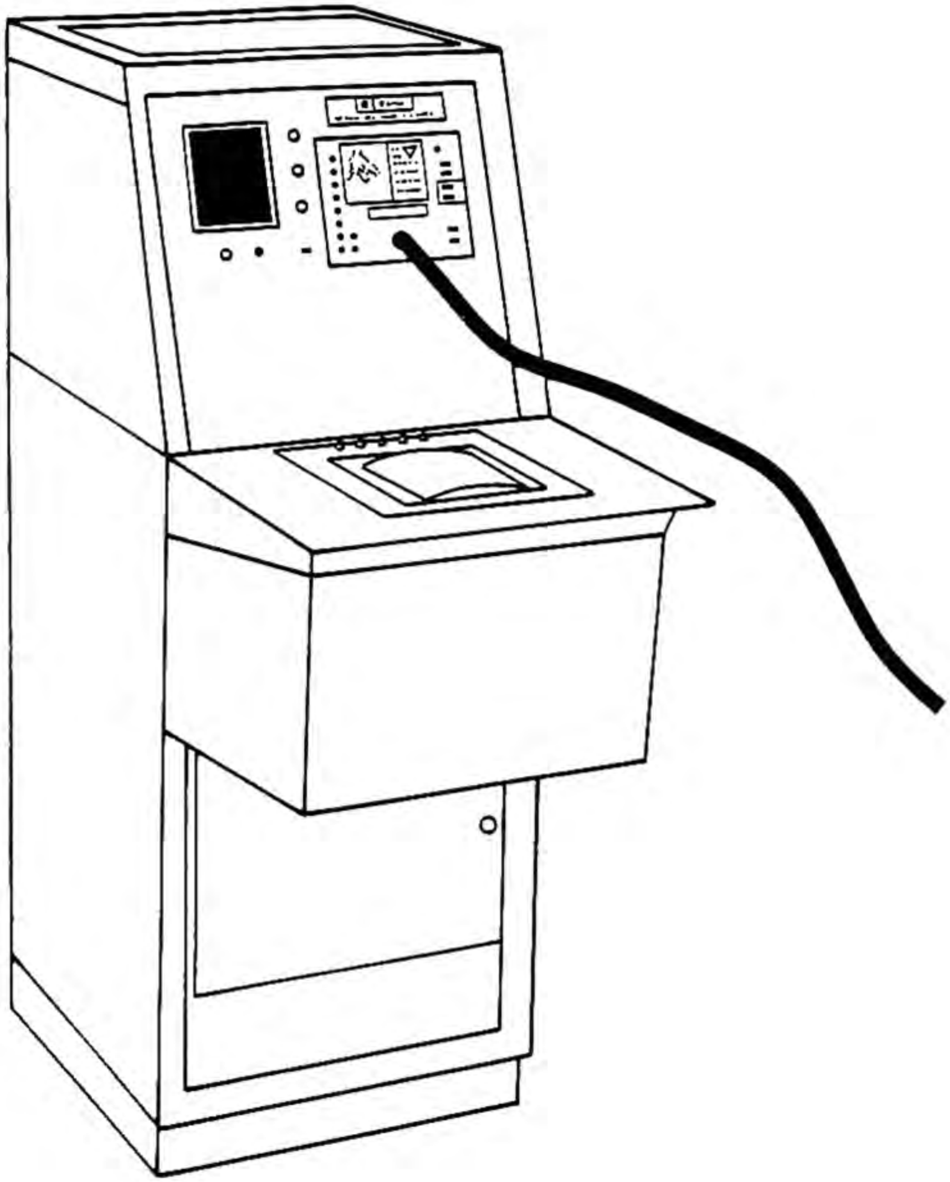
APPENDIX 7. Skinfold sites selected for measuring skinfold thickness in determining percent body fat.

SKIN FOLD MEASURING SITES



APPENDIX 7

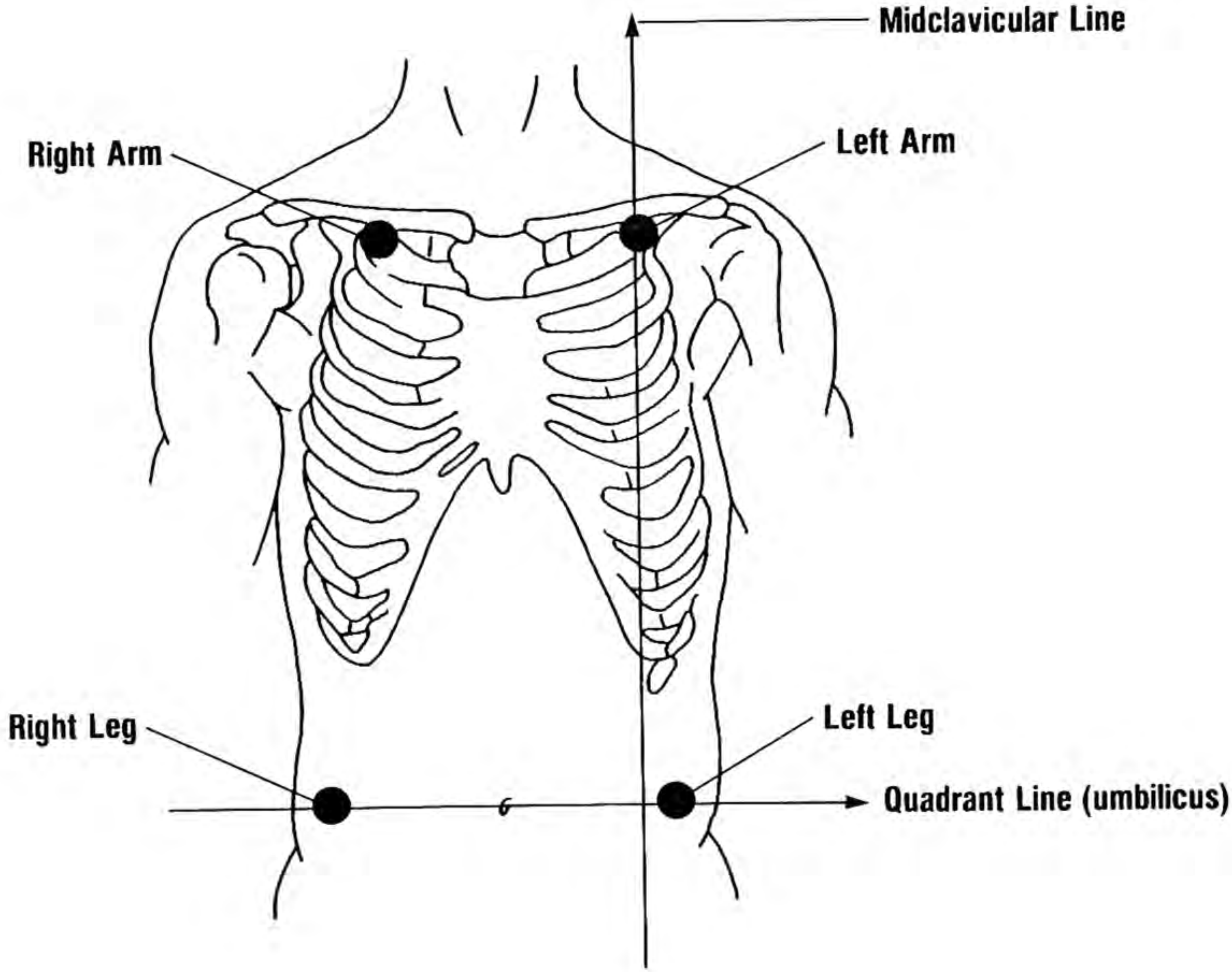
APPENDIX 8. Quinton Instrument Model 633 3-channel electrocardiogram (ECG) recorder and monitor.



APPENDIX 8

APPENDIX 9. Modified limb lead placement for electrocardiogram (ECG) monitoring.

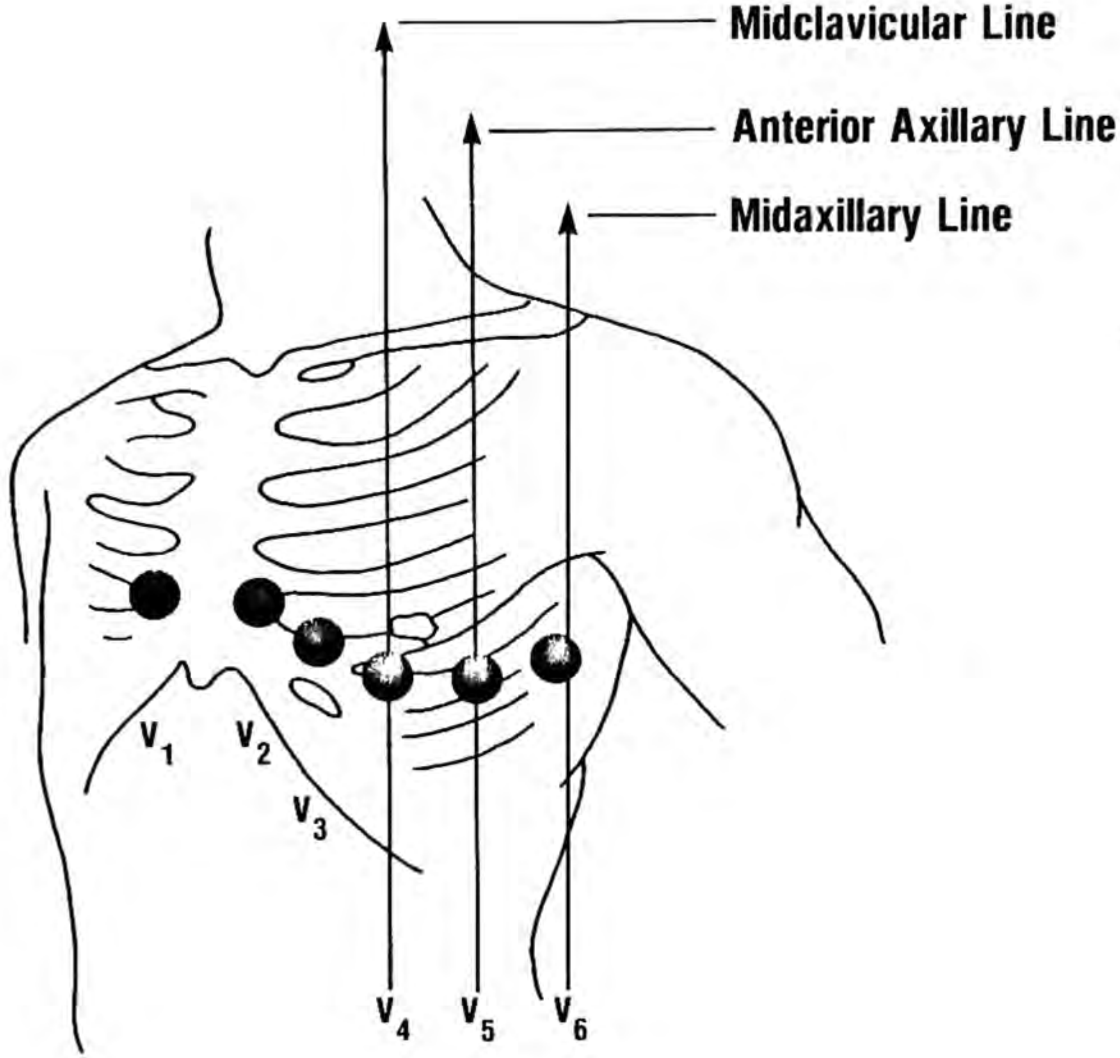
Taken from; Guidelines for graded exercise testing. In: Exercise Technician Workshop Notebook. Wake Forest University, 1978.


Midclavicular Line
Right Arm
Left Arm
Right Leg
Left Leg
Quadrant Line (umbilicus)

APPENDIX 9

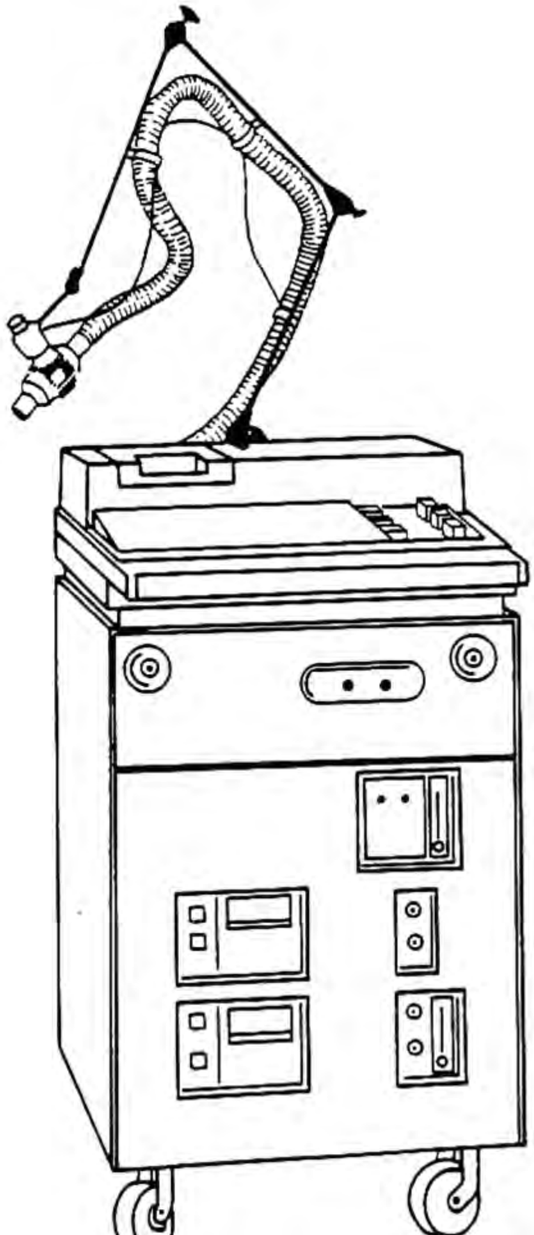
APPENDIX 10. Chest lead placement for electrocardiogram (ECG) monitoring.

Taken from; Guidelines for graded exercise testing. In: Exercise Technician Workshop Notebook. Wake Forest University, 1978.


Midclavicular Line
Anterior Axillary Line
Midaxillary Line
V_1
V_2
V_3
V_4
V_5
V_6

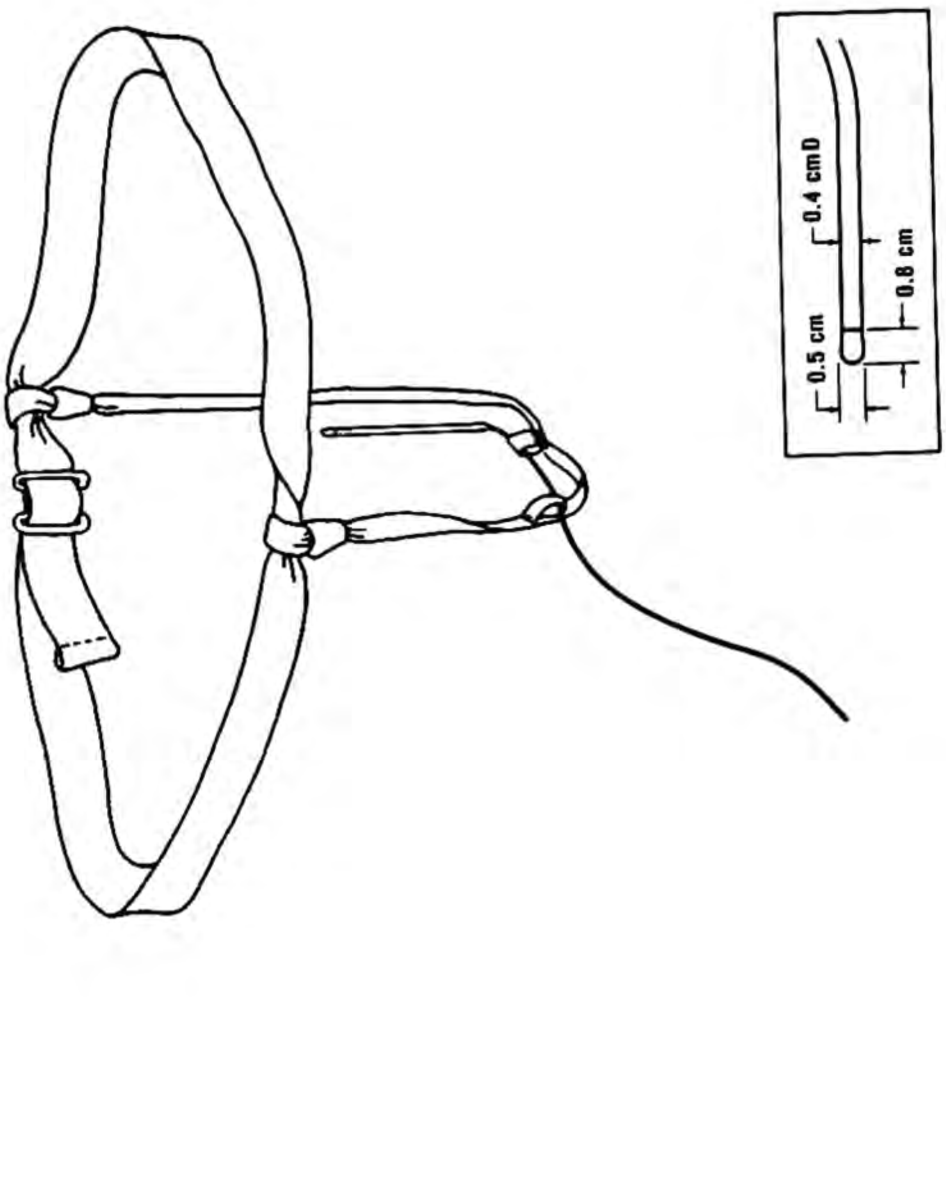
APPENDIX 10

APPENDIX 11. Beckman Metabolic Measurement Cart (MMC). Used for Respiratory gas analyses on all subjects.



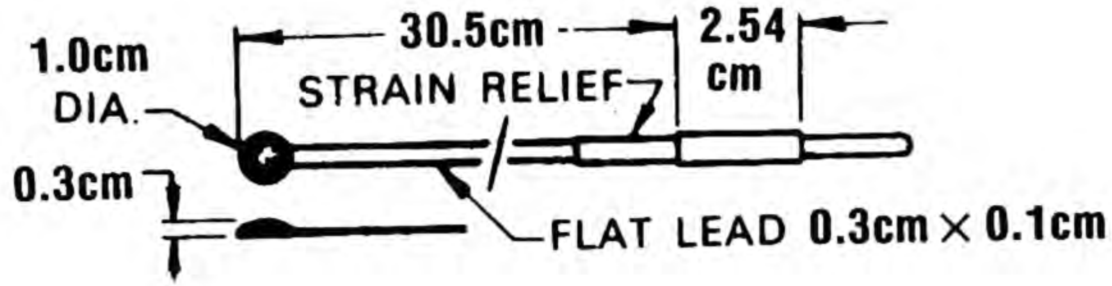
APPENDIX 11

APPENDIX 12. YSI Series 400 rectal temperature probe for monitoring rectal temperature (T_{re}). Vinyl tip and lead. Harness and belt assembly used for maintaining placement of probe.



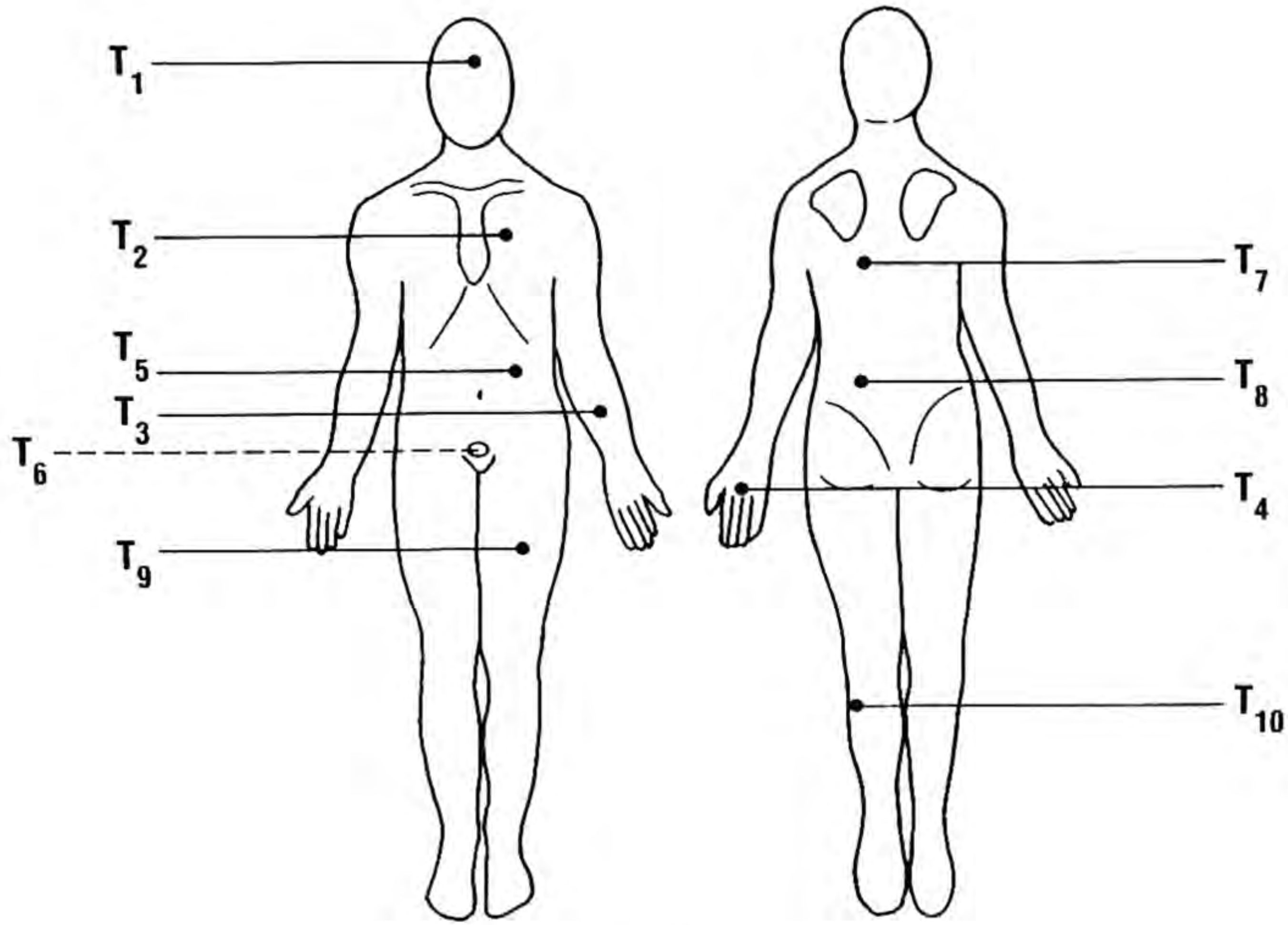
APPENDIX 12

APPENDIX 13. YSI Series 400 skin thermistors used for monitoring selected skin temperatures on all subjects. Stainless steel cup, epoxy backed with teflon-covered flexible wire.



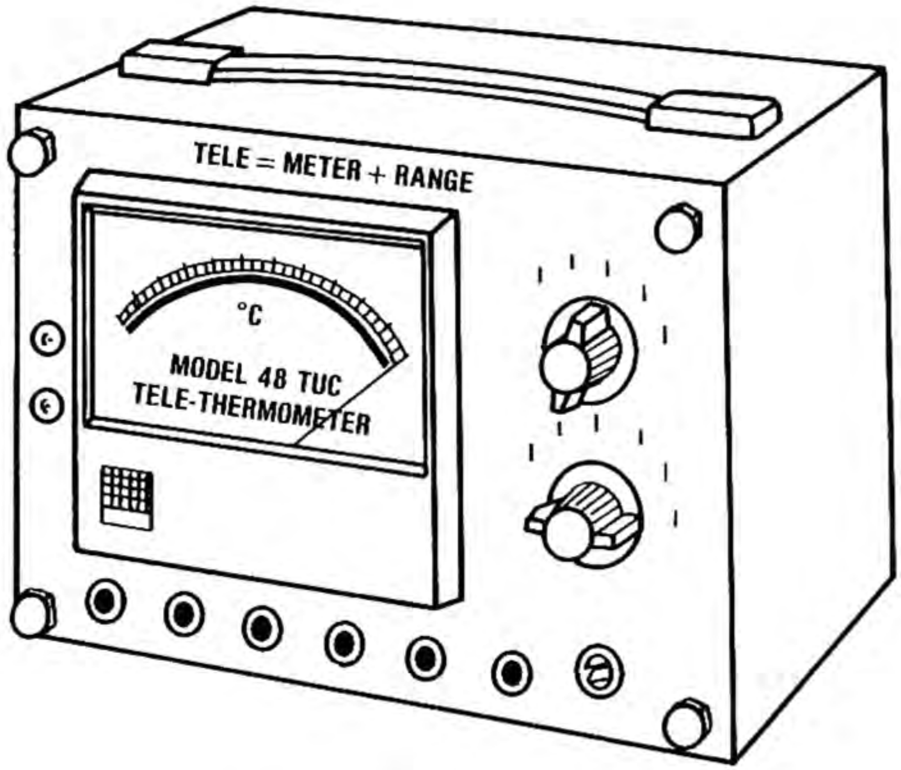
APPENDIX 13

APPENDIX 14. Temperature thermistor placement areas. T_1-T_5 and T_7-T_{10} identify skin thermistor sites and T_6 identifies the rectal temperature probe.



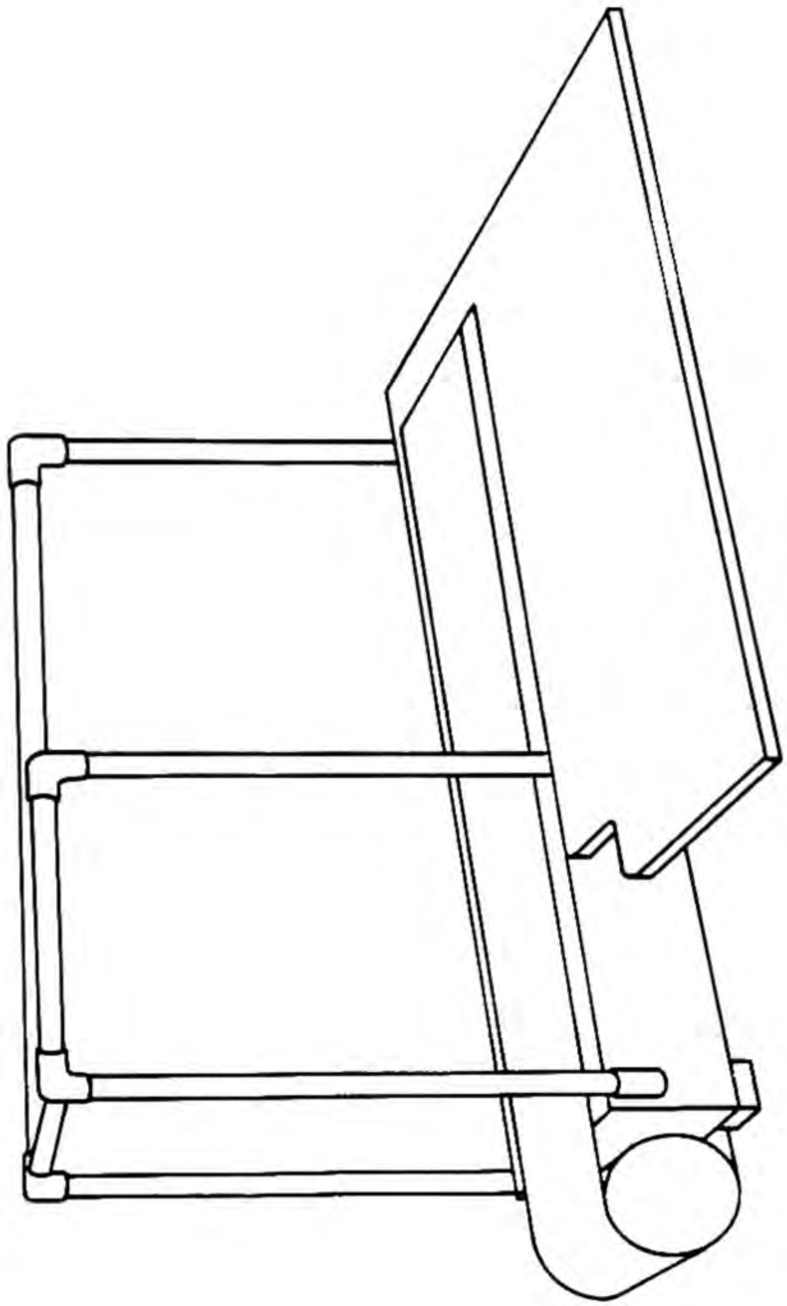
APPENDIX 14

APPENDIX 15. YSI Model 46 tele-thermometer. Battery powered instrument for measuring multiple ranges of temperature. Temperature indications obtained by using YSI 400 Series thermistors. Readability: ± .05°C. Accuracy: ± .15°C.



APPENDIX 15

APPENDIX 16. Quinton multistage treadmill, Model 18-60. Used with Quinton Instrument Model 633 3-channel ECG recorder and monitor. Treadmill speed, percent grade, and time of change automatic by pre-programmed computer card.



APPENDIX 16

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